Chapter 7
Technologies Affecting Quality

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Producers are constrained by the quality characteristics of the seeds available to them, as described in chapter 6. They cannot improve the intrinsic quality of corn, wheat, or soybeans once the seeds are planted. Yet they—and others involved in the distribution of grain—can prevent a deterioration in intrinsic quality and can determine the sanitary and some of the physical quality characteristics, At each step along the way, the technologies applied and the way they are used can prevent, or at least minimize, a loss of quality.

Farmers who run combines too fast, for example, can damage grain, especially as it dries, Grain that is either too dry or too wet when harvested is more susceptible to damage. Precleaning wet grain before it reaches the dryer would improve the quality substantially, yet few dryer operators choose to do this, Breakage during handling produces broken grains and fine materials, which increases storage problems and the risk of infestation by insects or mold. Cleaning and blending—the mixing of two or more grain lots to establish an overall quality--are the focus of many concerns about the declining quality of U.S. grain, and indeed sparked the Grain Improvement Act of 1986.

This chapter therefore looks at these numerous technologies that are applied to grain as it moves from the field to the export elevator or the unloading dock of a domestic food or feed manufacturer. Considered in turn are technologies for harvesting, drying, storing and handling, insect management, transporting, and cleaning and blending, The conditions farmers and handlers should strive for in one situation to maintain and deliver a quality product are not always appropriate in another case. Higher moisture content and temperatures are optimal for minimizing breakage of corn, for example, but not for safe storage. Giving producers enough information to consider all these interactions is one objective of this assessment.

HARVESTING TECHNOLOGIES

Harvesting can be defined as the process by which grains and oilseeds are removed from a plant, gathered, and physically removed from a field. The crop is also threshed (using combines to remove kernels from crop material), separated, and cleaned.

Self-propelled combines of either conventional or rotary design (figures 7-I and 7-2) harvest nearly all the grain produced in the United States. Rotary combines damage wheat and soybeans less than conventional combines do, although this is not the case for corn. Combine sales have dropped from a yearly average of about 30,000 units during the 1970s to fewer than 1,700 units in 1986. The weak market has slowed new combine development due to cutbacks in research and engineering funds.

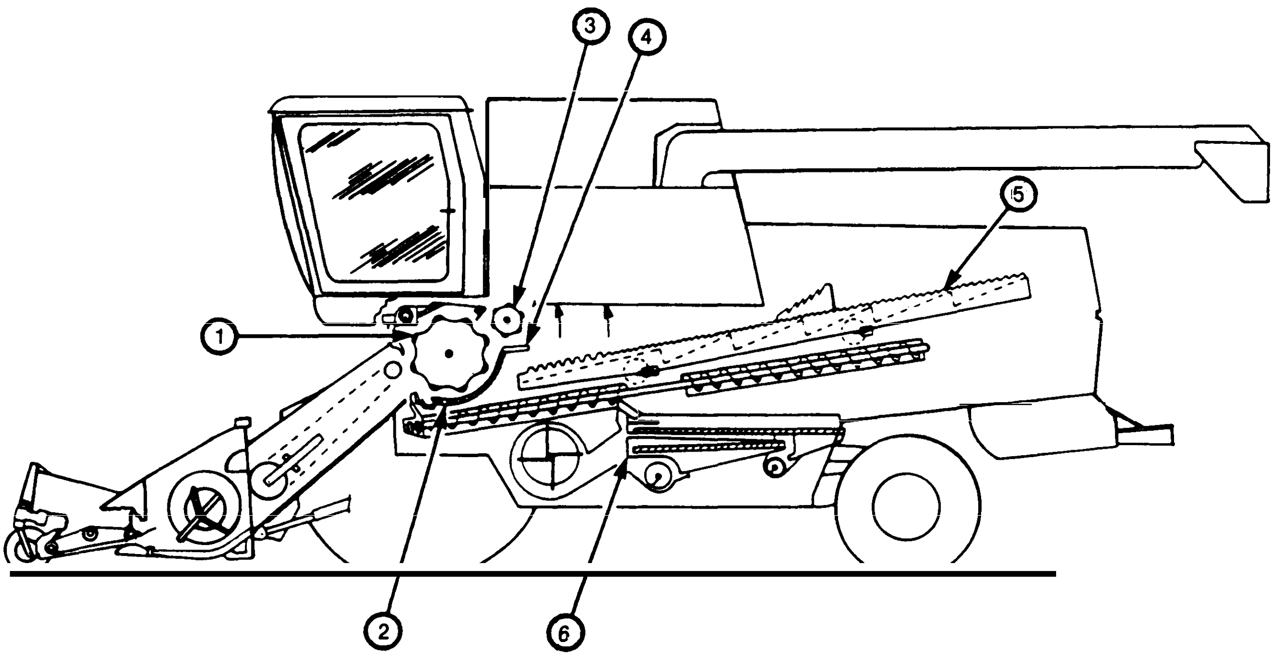
The first workable combine was developed and patented in 1836 (54) for use on small grains, In 1953 two individuals adapted the combine for use on corn, which until then had been harvested by picking the ear, The switch from picking corn by ear to combine shelling/harvesting increased corn production efficiency (52).

Rotary combines were introduced in the mid-1970s. The rotary's ability to use centrifugal separation resulted in fewer moving parts and reduced grain cracking. Today, both designs are used throughout the United States (57),

Current Technologies

Wheat combines differ from those used to harvest corn and soybeans. Conventional combines are built in "grain" or "corn/bean" configurations, with different separation functions in several areas, First, the concave in the corn/

Figure 7-1.—Conventional Combine



Equipped with windrow pickup header: 1—cylinder, 2—concave, 3—beater, 4—beater grate, 5—strawwalkers, and 6—shoe.

SOURCE: G.E. Frehlich et al., John Deere 8820 Titan II Self-Propelled Combine Evaluation Report No. 425, Prairie Agricultural Machinery Institute, Saskatchewan, Canada, 1985.

bean combine has wider gaps than in a wheat combine to allow the larger seeds. The concave transition grate is usually a finger-type unit on corn/bean combines and a cell-type configuration on wheat combines. Second, strawwalkers in corn/bean combines have a louvered bottom design because the rectangular openings in the bottom of wheat strawwalkers are prone to clogging by corn cobs. Finally, the chaffer sieve in corn/bean combines has deeper teeth on the louvers and wider spacing between louvers.

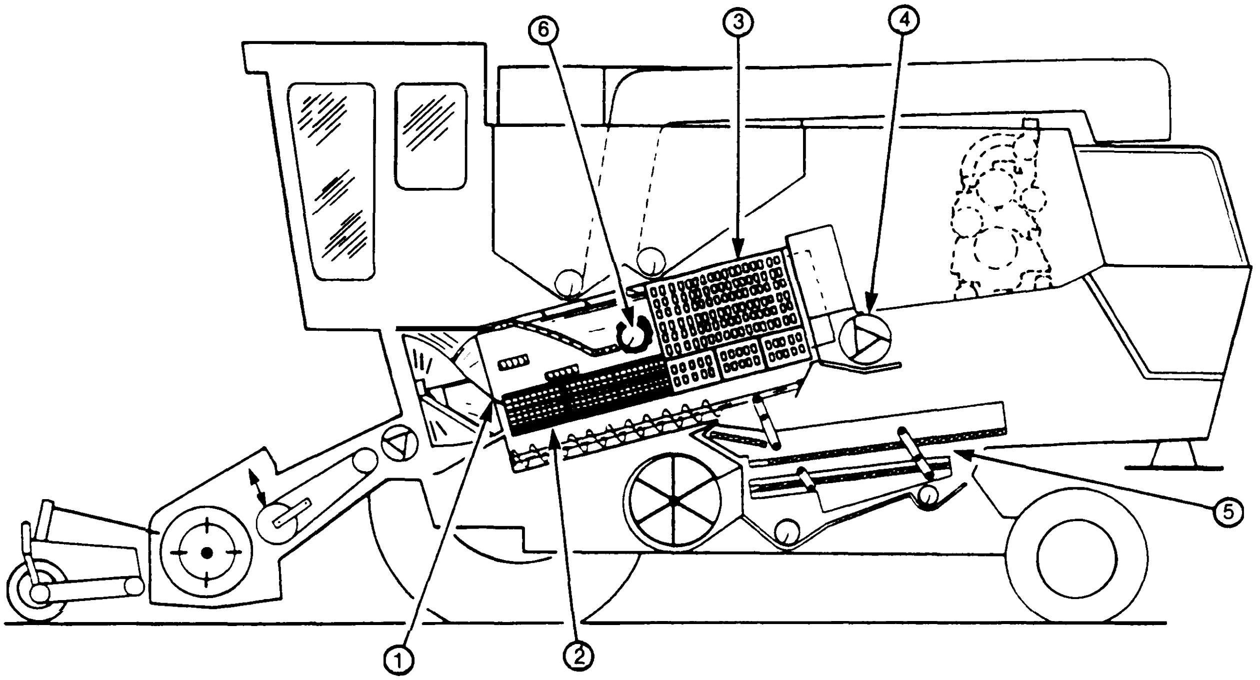
In areas of the United States that grow wheat as well as corn or soybeans, corn/bean combines are often used for harvesting wheat. The extent to which this compromises combine performance is not well documented. The expected impacts would be lower separation capacity and poorer cleaning due to the wide-spaced chaffer and higher cleaning-shoe loads produced by the corn concave.

Conventional self-propelled combines are most common, although variations in the system have been developed to deal with specific problems in certain areas of the country. Two such variations are the practice of windrowing wheat and the development of sidehill and hillside combines.

Windrowers in the Northern Plains States cut the wheat and place it in a swath on top of the wheat stubble, where it is later picked up by a combine equipped with a windrow pickup device (figure 7-1) that offers gentler handling than auger-type headers. Windrowing generally takes place when the wheat is at 30 to 35 percent moisture (54). Although windrowing is an additional expense, it interrupts weed seed development, thereby improving weed control in subsequent years; speeds wheat drying by up to 2 weeks and can shorten combining time considerably; and allows the crop to better withstand hail and high winds.

Combines with leveling in both pitch and roll modes have been developed to accommodate the tilling of 40 to 70 percent slopes in the Pa-

Figure 7-2.—Single-Rotor Rotary Combine



1—Rotor, 2—threshing concaves, 3—separating concaves, 4—rear beater, 5—shoe, and 6—tailings return.

SOURCE: G.E. Frehlich et al., Case IH Self-Propelled Combine Evaluation Report No. 531, Prairie Agriculture Machinery Institute, Saskatchewan, Canada, 1987.

cific Northwest. Such machines are heavily modified production combines with unique suspensions, drive lines, and feeder modifications. Sidehill combines with only roll leveling were developed in the mid-1970s for use on sideslopes of up to 20 percent, and are used primarily on the moderately rolling terrain of the Midwest.

Conditions Affecting Combine Performance

To be competitive, combine manufacturers must achieve an optimal balance between harvest capacity, harvest losses, grain quality, and operator safety and comfort. Combine fuel efficiency is also a concern, but is not the primary factor when designing combines. Conditions such as crop maturity, moisture content, standability, the presence of insects or disease, and the amount of weeds in the field are the main influences on combine performance.

Maturity and Moisture

Physiological maturity occurs when grain has reached its maximum dry weight. Thus, the grain's moisture content at harvest directly affects the amount of kernel damage produced through combining.

Corn maturity is obtained at about 30 to 35 percent moisture. While corn can be harvested at this point, the soft pericarp will de damaged. In the Midwest, harvesting is generally not recommended until the corn has field-dried to 26 percent moisture. In some parts of the United States, such as south Texas, corn field-dries to acceptable moisture levels and is not a problem. In the Northern States, however, obtaining 26 percent moisture is not possible during wet fall harvest periods, and corn must be harvested at higher moisture contents.

It is generally recommended that soybeans not be harvested until they reach 13.5 percent moisture. Soybeans readily absorb moisture overnight and during high humidity periods. After first being field-dried to 13.5 percent, soybeans can be harvested at moistures up to 15.0 percent. Soybeans at 14.4 percent moisture in the morning can easily dry to 11.4 percent by afternoon (11). Soybeans below 12 percent moisture are exceptionally susceptible to shatter loss during harvest.

Weeds

The main factor affecting combine cleaning performance is the amount and type of weeds present in the field at harvest. Weed control is one of the most serious problems facing many U.S. wheat-producing areas and southeastern soybean-producing areas, where a warm wet climate is conducive to weed growth. The amount of weeds affects not only yield, but also the amount of foreign material present in the harvested grain and the combine's ability to remove this material.

Weeds types have a direct bearing on yield and cleanliness. For example, the number of Hemp *sesbainia* in soybean fields has a direct effect on the amount of foreign material in combine samples (45). At 650 plants per acre, 0.8 percent foreign material was found; at 52,270 plants per acre, foreign material increased to 20,3 percent. In weedy fields farmers usually increase cylinder/ rotor speed to force the weed debris through the combine, but this can lead to increased grain damage.

One way to reduce the amount of foreign material in soybeans due to weedy conditions is to reduce the combine's ground speed. It has been found, however, that in weedy fields (compared with weed-free ones) 50 percent or more of the soybean pods are located on the lower 6 inches of the plant. Thus, the combine operator has to cut extra low, which increases the chance of picking up more soil.

Bromus sacalinus (cheat) is a major problem for winter wheat producers in the central Plains. One study found that between 66 and 99 percent of the cheat was introduced into the combine and 41 to 91 percent was delivered to the clean grain bin (18). Several combine modifications have tried to overcome this problem. Three cascade gaps in the cleaning shoe have been introduced in some regions. Other modifications include secondary cleaners and precleaning grain prior to delivering it to the cleaning shoe.

The process of modifying combines to adequately harvest clean wheat from weedy fields has been complicated by the trend toward smaller wheat kernel size, which is a concern because the seeds of most grassy weeds are smaller and lighter than wheat. Thus, the smaller wheat kernel size reduces the margin between wheat and weed size and therefore increases the difficulty of cleaning within the cleaning shoe (57).

Timeliness of Harvest

Timeliness of harvest often takes precedence over other factors such as the optimal moisture content needed for reduced breakage or lower field losses. Everywhere in the United States field conditions will permit harvesting for only a limited number of days. For example, in central Illinois, September and October have had 16 harvesting days in 8 years out of 10, based on statistical weather records (48,65).

Producers must therefore match combine size and the number of combines available to the number of days required to harvest the total acreage. Thus, when combine capacity is not available, long hours must be spent harvesting, which cannot be delayed because of grain moisture. The result of this dilemma is that producers often push the moisture limits, accept higher levels of kernel damage, and do not adjust combines as crop conditions vary.

In spite of the demands placed on the combine for high-capacity harvesting with minimal loss, field harvesting is only part of the total operation. Trucks, wagons, and drivers must be available to provide timely combine-tank unloading. If the crop must be hauled to a grain elevator, long truck lines can slow the harvest. Thus, it is essential to match hauling, drying if needed, and storage capacity with harvesting capacity.

A large percent of the harvest in the Great Plains is accomplished through custom wheat harvesting. The biological ripening of wheat begins in Texas and proceeds up through the Great Plains, This creates the opportunity for combines to follow the harvest. With custom combines concentrated where the crop is ripe, wheat harvest is completed rapidly and the crops' exposure to the elements is lowered.

Combine Adjustments and Operator Proficiency

The combine is the most demanding machine to operate on most farms in terms of operational workload and knowledge required for adjustment and maintenance, Modern combines provides at least 25 adjustments for tailoring the machine to specific conditions. Seven to ten of the most frequent adjustments are accessible from the operator's seat. Operators must constantly monitor ground speed, cutting height, reel speed, and reel height as the machine moves through the field. In addition, crop conditions can demand readjustment within the same field on the same day.

Cylinder/rotor speed can be adjusted by the operator and varies by crop, varieties, and moisture content. Generally, as moisture decreases, threshing speed should also be decreased, Concave settings must always be slightly larger than the size of the grain being threshed. A concave setting that is too narrow causes severe kernel grinding-like damage; if it is set too wide, kernels will be left in the head, on the cob, or in the pod, contributing to high threshing losses,

The extent to which combine operators understand and appreciate the interactions between combine components and adjustments varies widely. Because of the ease by which a nonoptimal cylinder/rotor speed can be confused with an incorrect concave setting, considerable operator experience is required when the goal is to maintain low grain damage and low header, threshing, and separating losses.

Effects of Harvesting Technologies on Grain Quality

The primary quality factors affected by combine harvesting are grain damage (which includes damage to the pericarp, broken kernels, internal cracks, and splits) and cleanliness. Grain damage is linked with threshing and handling components within the combine; cleanliness can be attributed to header height and to separating and cleaning components.

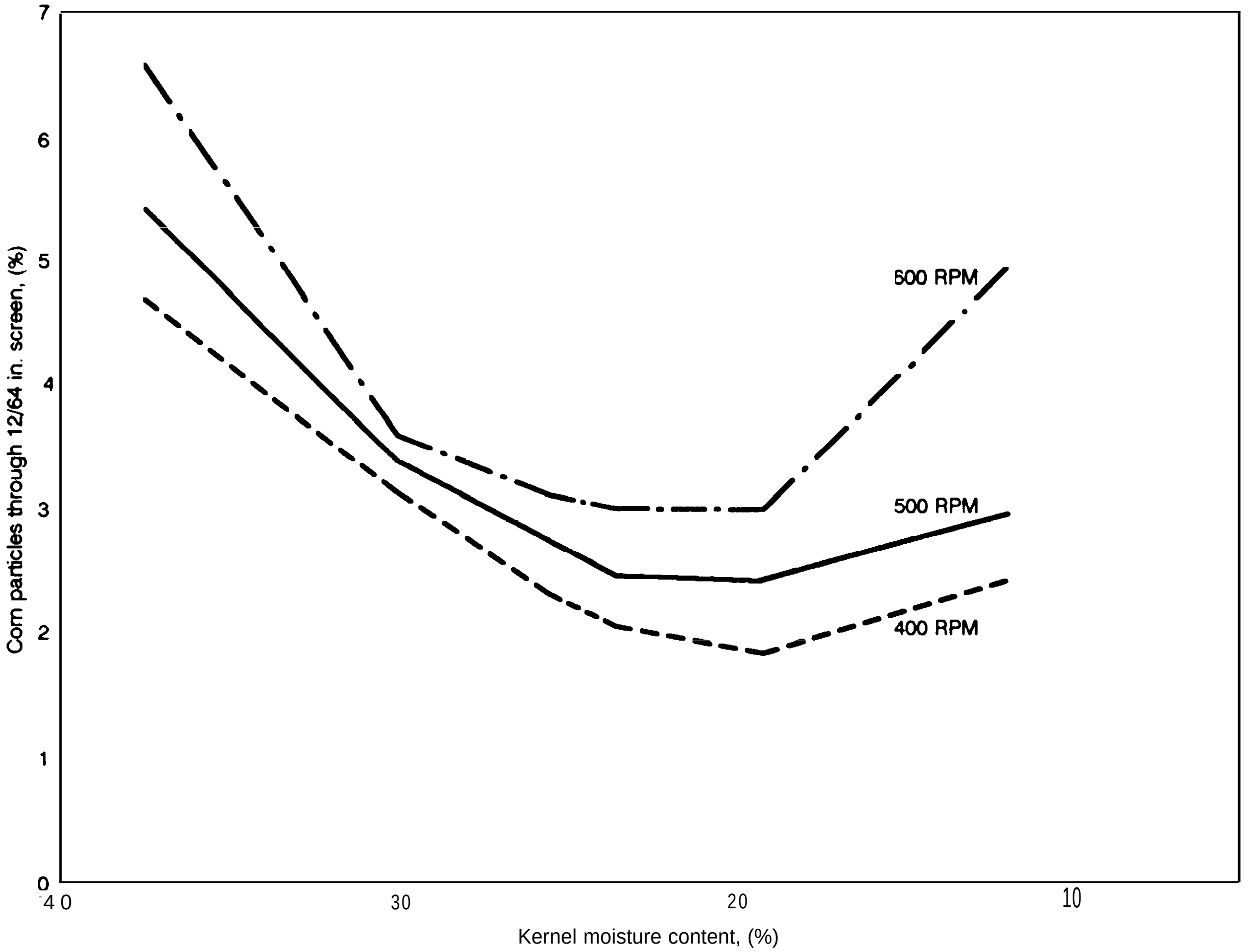
Grain Damage

Cylinder speed, moisture at harvest, and the amount of grain damage are all interrelated. In general, damage occurs whenever grain is harvested. It increases significantly, however, on extremely wet or extremely dry grain. When grain is harvested at high moisture levels, the kernel is soft and pliable. Moist kernels deform easily when a force or impact is applied, and a greater force is needed to thresh wet kernels than dry ones, so they suffer more damage. Drier kernels, however, can break when the same force is applied, Therefore, optimal conditions exist for each grain when cylinder speed and moisture are balanced.

The impact of cylinder/rotor speed on corn breakage varies by moisture level (figure 7-3), As moisture decreases, the impact increases. Breakage is higher at extremely high and low moistures regardless of cylinder/rotor speed. For wheat, the same principles apply: Cylinder/rotor speed increases wheat breakage, and the impact is more pronounced on wheat moistures of 14.6 percent than 18.9 percent, For all grains, cylinder/rotor speed must be reduced at lower moisture levels to minimize grain damage.

The type of combine (rotary or conventional) affects grain damage in wheat and soybeans. Several studies have demonstrated reduced damage from some rotary combines compared with conventional combines, One study on the amount of split soybeans from two types of rotary combines and a conventional combine

Figure 7-3.—Corn Breakage v. Kernel Moisture Content for Laboratory Rasp Bar Sheller Operated at Varying Speeds



SOURCE: G E Hall and W H Hohnson, "Corn Kernel Crackage Induced by Mechanical Shelling," American Society of Agricultural Engineers 13(1), 1970

demonstrated the reduced amount of splits using rotary combines (47). Studies on rotary and conventional combines for wheat indicate a two-third reduction in grain damage using rotary combines (57). Studies of corn breakage using the two combine types have not shown any significant differences (52).

Cleanliness

Three combine components directly affect the combine's ability to harvest and deliver clean grain: header height, separating, and cleaning shoe.

Header height must be set to operate near or at ground level. This is particularly true when harvesting certain varieties of soybeans with pods set very low on the stalk. Cutting below the lowest pod or wheat head inadvertently introduces some soil into the combine. Most soil is aspirated out the rear of the combine unless it is about the same size as the kernel. In these cases, soil particles pass through the cleaning sieves with the grain.

Material that is fed onto the cleaning shoe after passing through the cylinder concave or strawwalkers is divided into three streams. Whatever does not move through the top sieve (chaffer) passes out the rear. Grain and other plant parts that pass through the chaffer but not the cleaning sieve are routed back to the cylinder/rotor for rethreshing. Grain that passes through the cleaning sieve is conveyed to the clean grain tank. Aspiration (using fans) is also used in this process to remove light material, If the fans are set too high, grain maybe drawn off along with the lighter material.

This process removes material larger than the grain (such as plant parts) and material significantly smaller (like sand and dirt), Sloping terrain, as previously discussed, can affect this process. In wheat, the amount of foreign material increases as the angle of the cleaning shoe decreases (59). Side slopes also create problems since the tendency is for material to congregate on the downhill side of the cleaning shoe.

New and Emerging Technologies

Changes in harvesting technology have been evolutionary rather than revolutionary, For example, the rotary combines were widely publicized as a major breakthrough, yet studies of centrifugal separation had been conducted some *15* years earlier. With declining combine sales over the past *8* years, revolutionary changes are even less likely.

Current harvesting technology provides combines capable of obtaining low grain damage levels and reduced foreign material with acceptable losses, The problem remains in getting operators to run the machines at the lowest grain damage level the combine is capable of delivering. The major advance in this area is through new control systems and automation,

One recent aid for improving harvesting has been the introduction of grain loss monitors. These are mounted behind the combine's separation and cleaning sections and electronically sense the number of kernels that hit a small acoustical pad. Loss monitors have been marketed as a means of reducing threshing and separating losses. They can, however, aid operators in reducing threshing speed until losses become noticeable, thus reducing grain damage. Since grain damage increases as threshing speed rises, cylinder/rotor speed must be reduced as grain dries until threshing losses, observable on the grain loss monitor, start to increase *(52),*

Information sensors are commonly provided as original equipment on newer combines. Such sensors include digital readout of cylinder/rotor speed, fan speed, feeder shaft speed, reel speed, engine speed, and ground speed. Several manufacturers now have warning lights for speed reductions of the fan, cylinder/rotor, discharge beater, straw chopper, feeder, rear beater, clean grain elevator, and return elevator. When this information is received, operators can now make adjustments from the operator station, but they still must decide if changes are needed.

Low-cost microcomputers and improved sensors mean many of the current operator decisions will soon become automatically controlled by computers. A limited number of computer-assisted programs are already available to assist operators in selecting proper combine settings.

DRYING TECHNOLOGY

Cereal grains and oilseeds are harvested in the United States at moisture levels too high for long-term storage or even short-term storage and transportation within the marketing system. Corn, which is harvested at 20 to *30* percent moisture, must be dried to 14 to 15 percent for safe storage. Wheat and soybean harvest moistures are substantially lower than corn, with safe storage levels marginally lower than harvest moisture. Since wheat (and, in some cases, corn and soybeans) dries naturally in the field in some parts of the country, this discussion mainly concentrates on drying technologies as they relate to corn.

Considerable moisture is removed from grain during drying. When taking corn from *25* to 15.5 percent moisture, 122 kilograms of water are removed per metric ton. Drying grain in the United States takes place on farm as well as off farm in commercial handling facilities using ambient air as the drying medium. On-farm drying systems are usually lower in throughput than off-farm units and frequently employ lower drying-air temperatures.

Dryer design depends on grain type. The requirements for drying-air temperature, airflow rate, and the time the grain remains in the dryer differ for wheat, corn, and soybeans. Drying wheat in a corn dryer without modification will lead to a significant decrease in wheat quality,

It is generally agreed that the bulk of grain quality deterioration happens during drying ***(6). Too*** frequently, excessively high-drying-air temperatures and airflows are used to speed the process. This leads to excessive stress cracking in corn and soybeans and degradation in the milling quality of wheat.

On-Farm Drying Systems

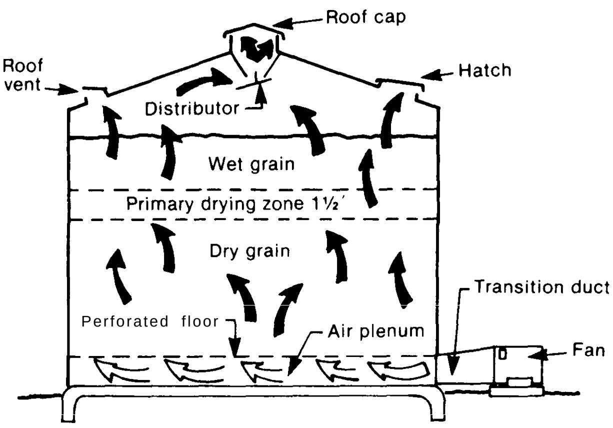
Cereal grains and oilseeds are mainly dried on-farm in the United States. Indiana is typical: In 1984, less than 5 percent of the States's corn was dried off-farm (37). On-farm systems fall into three broad categories: bin dryers, non-bin dryers, and combination systems.

Bin Dryers

Bin dryer systems include: ***1)*** in-bin natural air, 2) in-bin low temperature, 3) solar, 4) in-bin storage layer, 5) in-bin counter-flow, and 6) batch-in-bin. They all use a bin to hold wet grain as it is dried. The drying-air temperatures of the first four systems are relatively low, while the last two need temperatures as high as ***70 "C.***

In-bin natural air, low temperature, and solar drying systems are similar (figures 7-4). Wet grain is placed in a bin to a depth of ***2.5*** to ***5.0*** meters and slowly dried using an external fan as the airflow source. Each system can produce high-quality grain. However, minimum airflow rates are critical for their success; these depend on the initial moisture content, harvest date, and environmental conditions. Airflow rates vary by location and, consequently, farmers

Figure 7-4.—in-Bin Natural. Air Grain Drying System



SOURCE F W Bakker-Arkema, "Grain Drying Technology, " background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988

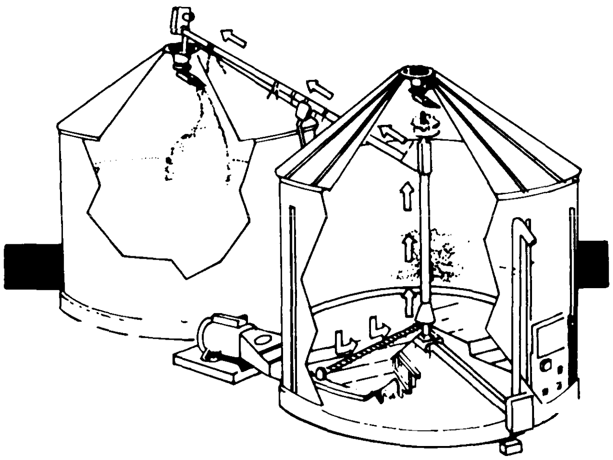
need considerable expertise to operate these systems properly by selecting the correct airflow rate. Slower drying than the required rate can lead to grain molding before safe storage levels are reached.

In-bin storage layer drying differs slightly from natural air drying. Rather than filling a bin all at once with wet grain, successive layers are placed in the bin after the preceding one has almost reached the desired moisture content. Like natural air drying, this drying system has low capacity, requires considerable operator expertise, is energy-efficient, and can produce excellent quality grain when operated properly.

In-bin counter-flow drying is relatively new and consists of two bins (figure 7-5). One is a heated air in-bin counter-flow dryer and the other is a natural air in-bin dryer and cooler. Wet grain is loaded into the first bin and dried until the bottom ***10*** centimeters has reached ***16*** to ***18*** percent moisture. The partially dried, hot grain is then moved to a second bin for slow final drying and cooling. The automatic nature of this process, along with the ability to produce quality grain at fairly high capacities, has contributed to the commercial success of in-bin counter-flow dryers.

Batch-in-bin dryers differ from in-bin counter-flow dryers in that they lack the second dry-

Figure 7-5.— In-bin Counterflow Grain Dryer



SOURCE F.W. Bakker-Arkema, "Grain Drying Technology, " background paper prepared for the Off Ice of Technology Assessment, U.S. Congress, Washington, DC, 1988

ing and cooling bin, Airflow rates and drying temperature are similar, but the energy efficiency as well as the grain quality characteristics are poorer ***(4).***

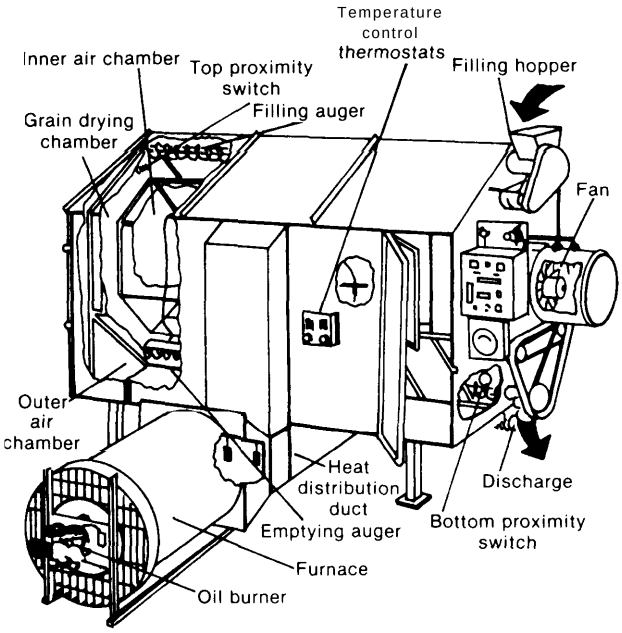
Non-bin Dryers

Non-bin dryers are either portable batch or continuous-flow dryers. Over half the U.S. grain crop is dried (both on and off farm) in these two types ***(6).*** They utilize drying air temperatures in excess of ***100 'C*** or more and airflow rates over ***110*** cubic meters per minute per ton. Thus, the drying rate is high, but the resulting grain quality is often lower,

portable batch dryers consist of a plenum surrounded by a ***30*** to ***40*** centimeter grain column (figure ***7-6).*** Hot air traverses the grain layer quickly and in the process overheats and overdries part of the grain column. The batch is removed from the dryer as soon as the desired final moisture content and temperature are reached. A portable batch dryer is comparable to in-bin batch dryers except that grain is dried at higher temperatures and airflow rates due to the reduced depth of the grain layer.

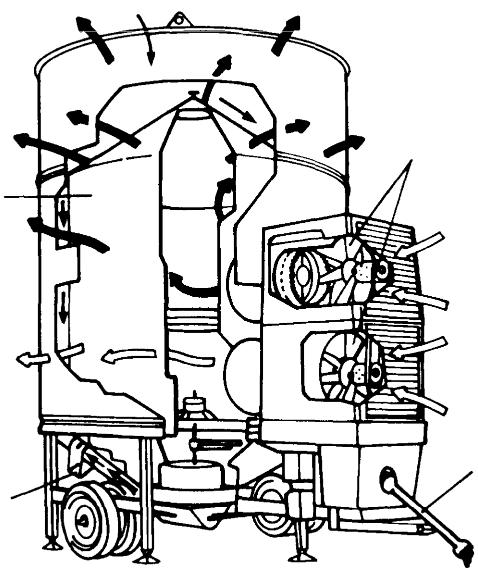
Continuous-flow dryers are predominantly of the crossflow type (figure 7-7). The drying air flows perpendicular to the grain flow through the dryer. The plenum/grain column

Figure 7-6.— Portable Batch Grain Dryer



SOURCE F W Bakker-Arkema, "Grain Drying Technology, " background paper prepared for the Office of Technology Assessment, U S Congress Washington, DC, 1988

Figure 7-7.—Continuous-flow Crossflow Grain Dryer



SOURCE: F W Bakker-Arkema, '"Grain Drying Technology, " background paper prepared for the Off Ice of Technology Assessment, U S Congress, Washington, DC, 1988 is similar to that in a portable batch dryer. Cooling takes place in the bottom one-third of the drying column. Airflow rates and drying temperatures are the same for both types; the only difference is the grain velocity.

Continuous-flow crossflow dryers do not dry grain uniformly because a large moisture gradient exists across the grain column when drying is discontinued. During the cooling cycle, the degree of nonuniformity decreases, but a definite moisture differential among kernels still exists when the grain leaves the dryer. In one study, when drying ***25*** percent corn at ***110*** °C to ***16*** percent average moisture, the corn's moisture content at the air inlet side of the grain column reached ***8*** percent. At the air outlet side, the grain was still at 22 percent, thus creating a moisture gradient of ***14*** percent ***(24).*** As table 7-1 indicates, part of the grain in a crossflow dryer approaches the drying-air temperature, which results in overdrying and sharp increases in breakage.

Combination Drying

Combination drying is a system in which high-temperature, high-speed batch or continuous-flow drying is followed by low-temperature, slower in-bin drying and cooling. This attempts to maximize the advantages and minimize the disadvantages of the two systems.

Combination drying is mainly used for corn. When corn is harvested in the 22 to 35 percent range, it is dried in a high-temperature dryer to an intermediate moisture content of ***18*** to ***24*** percent and then moved hot to an in-bin dryer and slowly final dried and cooled. The in-bin dryer usually is a natural air dryer. The best known type of combination drying is dryeration (figure 7-8). The two main advantages of combination drying over non-bin dryers are the increased energy efficiency and improved grain quality.

Table 7-1.—Grain Temperature, Moisture Content, and Breakage Susceptibility at Different Locations in the Grain Column of a Crossflow Dryer

Distance from air inlet (cm)	Grain temperature (°C)	Moisture content (in percent)	Breakage susceptibility (in percent)
1.25	102	10	48
7.50	78	20	11
13.75	51	24	10

SOURCE: R J. Gustafson et al , "Study of Efficiency and Quality Variations for Crossflow Drying of Corn, " ASAE Paper No 81-3013, 1981

Off-Farm Drying Systems

Grain dryers located off farm in commercial handling facilities are non-bin continuous-flow models. Three types are currently in use: crossflow, mixed flow, and concurrent flow.

Crossflow

Crossflow dryer design was discussed in the on-farm section, The distinguishing feature here too is the perpendicular direction of the grain and airflows, which results in nonuniform drying. Recent design improvements for off-farm crossflow dryers have improved grain quality and energy efficiency.

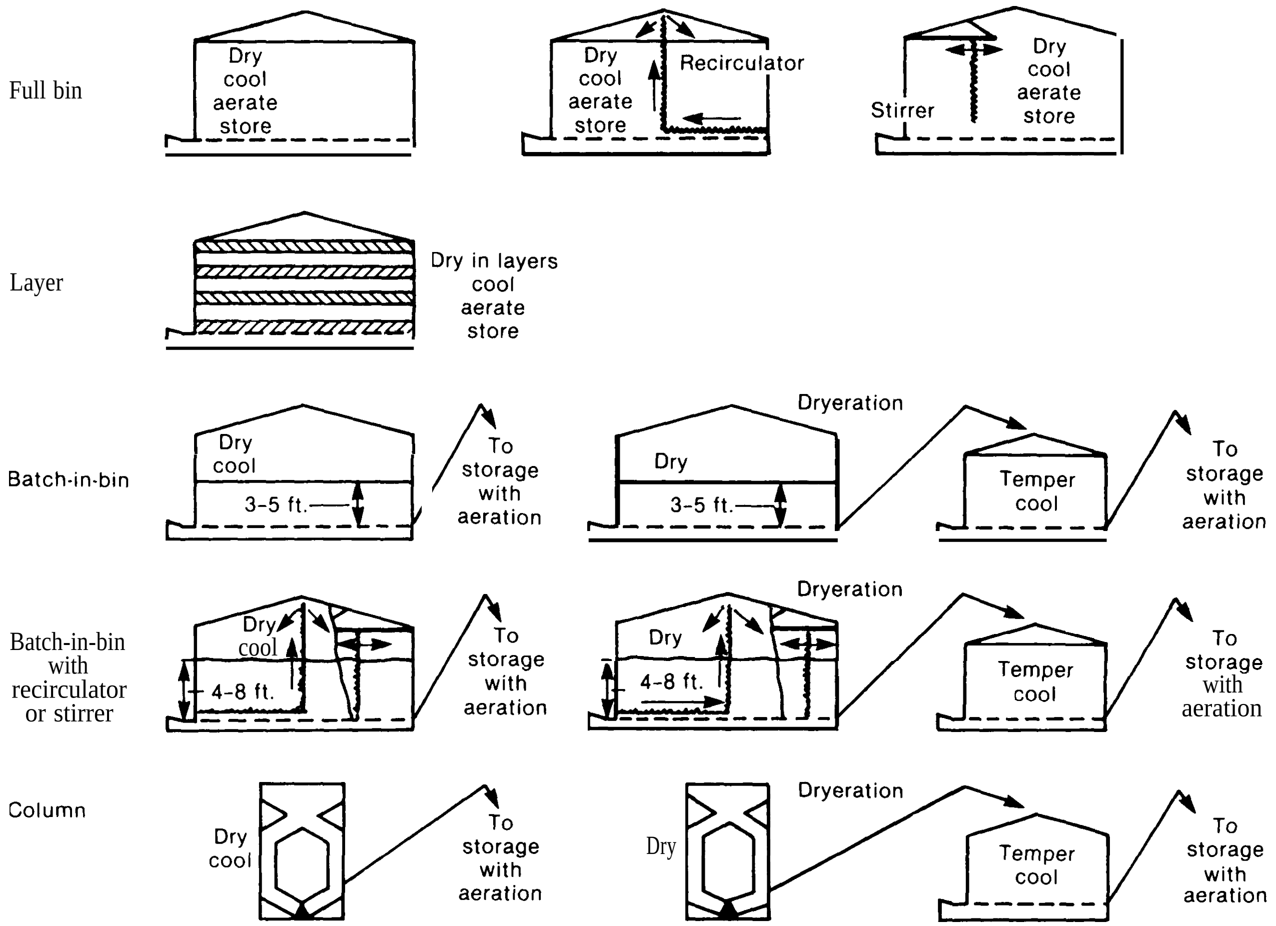
In a conventional crossflow dryer, the discharged air is only partly saturated, Recycling part of the drying air and all of the cooling air greatly decreases energy requirements. Along with air recycling, airflow reversal has been incorporated in some crossflow dryers in order to offset the large moisture differential in the grain column. Placing a grain inverter in the grain column is less expensive, but also less effective. Grain inverters turn the overheated grain at the air inlet side to the air exhaust side of the column and thus minimize overheating ***(50).*** Crossflow dryers without air reversal or grain inverters have moisture gradients across the drying column as large as 20 percent and grain breakage as high as 50 percent (24).

Two new features added recently to the basic cross flow design—differential grain speed and tempering—improve grain quality ***(40).*** A crossflow dryer incorporating air recycling, air reversal, differential grain speed, and tempering is commercially available, but its high initial cost is preventing general acceptance.

Mixed Flow

Mixed-flow dryers are also called cascade or rack-type dryers, Grain is dried by a mixture of crossflow, concurrent flow, and counterflow

Figure 7-8.— Dryeration Grain Drying Systems



SOURCE F W Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Off Ice of Technology Assessment, U.S. Congress, Washington, DC 1988

drying processes. The grain flows over a series of alternate inlet and exhaust air ducts. This results in fairly uniform drying and therefore a relatively uniform moisture content and quality. The drying temperature in mixed-flow dryers is higher than in crossflow ones because the grain is not subjected to the high temperature for as long.

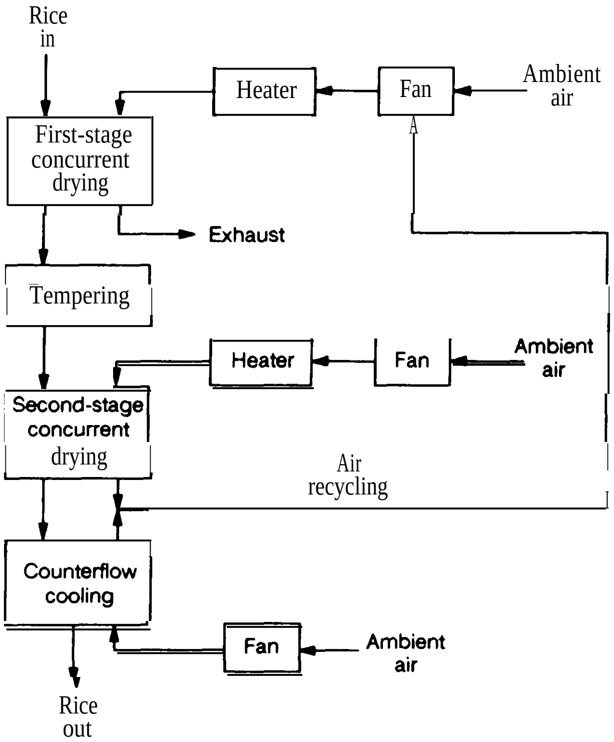
Mixed-flow dryers are more expensive to manufacture and require more extensive air pollution equipment. For these reasons, the number of mixed-flow dryer manufacturers has decreased in the United States. In other countries, mixed-flow dryers remain the predominant large continuous-flow dryer ***(6).***

Concurrent Flow

In concurrent-flow dryers the grain and drying air flow in the same direction (vertically), Cooling occurs in a concurrent-flow cooler in which the grain and air flow in the opposite direction. Commercial concurrent-flow dryers consist of two or three concurrent-flow drying zones and one counterflow cooler (figure 7-9).

The most distinguishing feature of these dryers is the uniformity of the process. Every kernel undergoes the same heating/drying/cooling process, unlike in crossflow and mixed-flow dryers. The drying-air temperature is much higher than in other dryers because the wet grain is subjected to the hot drying air not for

Figure 7-9.-Two-Stage Concurrent-Flow Grain Dryer With Counterflow Cooler and One Tempering Zone



SOURCE: F W Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U S Congress, Washington, DC, 1988

hours (crossflow dryers), or minutes (mixed-flow dryers), but only seconds. Thus, the grain does not approach the temperature of the drying air, as it does in other types.

The uniform, relatively gentle grain drying and cooling in concurrent-flow dryers results in dried grain of superior quality (table 7-2). Breakage susceptibility in concurrent-flow dryers is half that of mixed-flow and one-fourth that of crossflow dried corn.

Conditions Affecting Dryer Performance

Dryer performance is affected by physical, biological, economic, and human factors. Each can have an impact on grain quality.

Physical Factors

The physical factors affecting drying performance are climate and weather. The climate determines the type of hybrids that can be grown in a particular region, the expected moisture content range, and the weather at harvest. Initial grain moisture entering a dryer has a significant effect on dryer performance. Not only are dryer capacity, energy consumption, and operating costs influenced by the initial moisture, so is grain quality. When grain is harvested above or below its optimum harvest moisture, quality losses during drying increase (12). Thus, in Northern States, where harvest moistures frequently exceed optimum value, corn and soybean quality is inherently inferior to that of grains grown, harvested, and dried in the Central Corn Belt States.

Certain years will be wet in the summer and fall and result in grain with excessively high moisture content reaching the dryers, This leads to lower dryer capacity, higher energy consumption, higher drying cost, and decreased grain quality. Weather conditions have a direct effect on the performance of some on-farm bin dryers. These low-capacity systems may not be able to dry wet grain before molding sets in (58). Off-farm systems are less directly affected by weather conditions.

Biological Factors

Two biological factors affect dryer performance: grain type and genotype. First, wheat dries most rapidly and corn most slowly. A concurrent-flow dryer has a 23 percent higher throughput for wheat than for corn while operating at the same drying temperature. The maximum drying temperature for corn is substantially higher than that for wheat, thus affecting the quality of these two grains differently. Also, energy use is affected by grain type.

Genotype determines the drying rate of single corn kernels (64). Some genotypes dry slowly and others dry fast. Dryer capacity and fuel efficiency are higher with new genotypes. Drying rates for wheat and soybeans, however,

Table 7-2.—The Effect of Dryer Type on the Drying-Air Temperature, the Maximum Grain Temperature, and the Breakage Susceptibility of Corn

Dryer type	Drying-air temperature (c)	Maximum grain temperature (c)	Breakage susceptibility (percent)
Crossflow	80-110	80-110	20
Mixed-flow	100-130	70-100	10
Concurrent-flow	175-285	60-80	5

SOURCE F W Bakker-Arkema, ' Grain Drying Technology, " background paper prepared for the Off Ice of Technology Assess ment U S Congress, Washington DC 1988

are not influenced by genotype ***(46).*** Breakage susceptibility after drying also varies by genotype (5 I ***,63).*** Table 7-3 shows that a fivefold increase in breakage susceptibility may occur when switching genotype.

Economic Factors

Economics can affect dryer performance by influencing fuel prices and availability. The relative price of natural gas, fuel oil, liquid propane, and electricity varies from year to year. At the present time, natural gas is the least expensive and electricity the most expensive energy source in the United States. The type used affects dryer operation because it influences burner efficiency and drying-air quality.

Grain dryers are directly heated in the United States, while indirect heating grain drying systems are common elsewhere. Indirect heating uses heat exchangers and is less energy-efficient, more costly, and less grain polluting than direct heating. It is used to prevent absorption by the grain of polycyclic aromatic hydrocarbons contained in the drying air. Of the three fossil fuels commonly used in direct-heated dryers in the United States, only fuel oil causes hydrocarbon absorption by grain (35).

Table 7-3.–Breakage Susceptibility of Different Corn Genotypes

Genotype	Breakage susceptibility (percent)
FRB 73 FR 18.	23.5
FRB 73 PA 91	10.5
FRB 73 FR Mo 17	7.5
FR Mo 17 x Fr 634	4.3

SOURCE M R Paulsen "Corn Breakage Susceptibility as a Function of Moisture Content '' ASAE Paper No 83.3078 1983

Human Factors

Grain drying is a complicated heat/mass/momentum transfer process of a heat-sensitive biological product and is frequently not well understood by the average dryer operator. At most commercial handling facilities, the dryer operator job is seasonal: It requires 12-hour days, 7 days a week, for 2 to 3 months. The pay rate is marginal and job training is usually by trial and error. Therefore, it is not surprising that dryer maintenance, supervision, and operation are far from optimal. All these factors affect the performance of the typical dryer with respect to capacity, energy efficiency, and grain quality (5). The most frequent mistake is using excessively high temperatures in order to increase dryer capacity.

Auxiliary Factors

Several auxiliary equipment (instrumentation) items influence grain dryer performance, Included here are the grain moisture meter, the air temperature meter, and the dryer controller.

Moisture meters are an integral part of the grain drying system. Electronic meters are used at grain handling facilities. Meters commercially available have an accuracy of ± 1 percent at the 13 to ***16*** percent moisture range and ± 2.5 percent at higher moistures ***(34).*** This contributes substantially to overdrying or underdrying of grain.

Air temperature measurement in a grain dryer is usually accomplished by a single thermocouple or thermistor, an acceptable practice when the temperature distribution in the dryer plenum is uniform. This is not the case, however, in many off-farm dryers (2) or on-farm models ***(58).*** Temperature differences of 20 to 35 °C in the plenum are not uncommon, resulting in overheating of part of the grain column and deterioration of average grain quality.

Controlling dryers is usually manual, and overdrying is frequently the result. Automatic control systems have recently become commercially available for in-bin and continuous-flow grain dryers. Their use leads to savings in energy and drying costs and limits the degree of overdrying and grain quality deterioration.

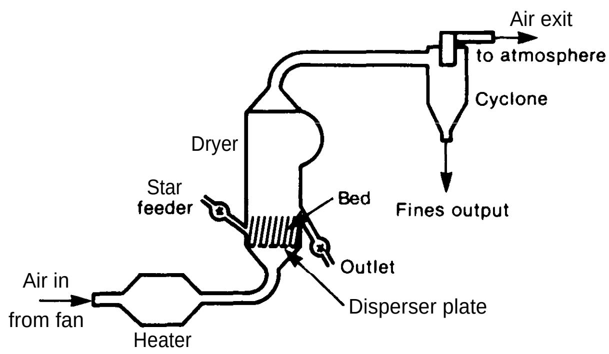
New and Emerging Technologies

Some new and emerging drying technologies have the potential for a significant impact on overall grain quality, especially in corn. Combination drying has already been discussed, along with its ability to improve corn quality at the farm level. Although the procedure has been known for a decade, it is still used only sparingly because of the more demanding logistics and additional grain-handling equipment required. No other promising technology appears to be on the horizon for on-farm grain drying.

Mixed-flow and concurrent-flow drying are off-farm drying technologies that produce higher quality grain than the standard crossflow dryers do. Both dryer types are commercially available in the United States. Their high initial cost (10 to 20 percent more than comparable crossflow dryers) has thus far prevented their widespread use. The same can be said for automatic moisture controllers. If the payback period of these technologies can be shortened, rapid market penetration can be expected (6).

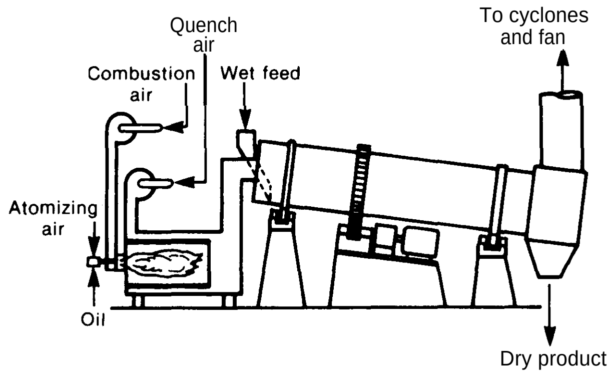
Two off-farm systems not used in the United States for corn are the fluidized-bed dryer and the cascading-rotary dryer (figures 7-10 and 7-11). A fluidized-bed grain dryer was at one time commercially available in the United States, but production was discontinued due to high electricity costs and excessive air pollution. The cascading rotary dryer is used in the United States to dry parboiled rice. High initial and

Figure 7-10.--Fluidized-Bed Grain Dryer



SOURCE: F W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

Figure 7-11.—Cascading-Rotary Grain Dryer



SOURCE: F.W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Off Ice of Technology Assessment, U S. Congress, Washington, DC, 1988.

maintenance costs plus high energy consumption characterize the U.S. rotary dryer design.

At least two companies have experimented with microwave grain dryers, but both have marketed commercial models without success. The advantages of low energy consumption and high grain quality were offset by high initial cost and low product throughput. It is unlikely that microwave grain dryers can compete with conventional drying techniques as long as the economic return of improved grain quality remains low.

A technology that could aid the drying rate of corn is the use of ethyl oleate and ethyl oleate/ethyl sterate mixture. Small-scale preliminary tests show that these chemicals applied to high moisture corn significantly increase the drying rate. The National Corn Growers Association is coordinating a series of larger scale tests of the chemicals at several universities.

STORAGE AND HANDLING TECHNOLOGIES

The usual surplus of U.S. grain means storage is required for longer and longer periods. With the increasingly large carryovers and the necessity to store more grain for more time, grain could be stored for a year or longer. Grain is a perishable commodity with a finite shelf life. Storage can only extend that shelf life, not improve it.

The total U.S. grain storage capacity in 1987 was about 23 billion bushels. Of this 14 billion are located on farm, and the other 9 billion off farm (56). Illinois leads in off-farm capacity, followed by Iowa, Kansas, Texas, and Nebraska (l). These States account for 53 percent of all off-farm storage. The number of off-farm storage facilities totaled 13,873 on December 1, 1987. Smaller proportions of wheat and soybeans are stored on farms (31 percent for wheat and 25 percent for soybeans) than of corn (47 percent), Major wheat-producing States in the Southern Plains tend to have more wheat stored off farm in commercial facilities than the Northern Plains States. Over 80 percent of the corn and soybean inventories are stored in the major corn- and soybean-producing States.

Current Technologies

Grain is stored in buildings or piles for future marketing and in transportation modes en route to destination. A wide variety of sizes and types of structures are used. The basic storage types can be classified as upright concrete or metal bins (vertical storage), buildings (horizontal or flat storage), and onground piles. The handling equipment used in each type is similar.

Handling Equipment

Handling equipment can be broken down into two categories, based on grain movement direction: vertical or horizontal (56).

The belt bucket elevator using an elevator leg is the primary means of moving grain vertically in commercial grain facilities. The leg consists of a vertical endless belt with buckets spaced evenly all along it. The buckets are filled by scooping up the grain at the bottom (boot) of the leg. Grain is discharged at the top by centrifugal force as the buckets pass over the top (head) pulley. Recent elevator designs have eliminated the need for traditional elevator legs by introducing incline belts to move grain vertically, After discharge, the grain flows by gravity through spouting or horizontally by belts or other conveying devices.

Commercial elevators using elevator legs or incline belts are available in any size and capacity to meet the vertical lift requirements of both large and small facilities. Elevators using legs can operate relatively economically at less than their rated capacity, unlike some other grain-handling devices. There is no problem with increased grain breakage resulting from legs being used at less than rated capacity. The amount of grain breakage occurring in elevators using legs is affected by the type and size of the buckets, belt velocity, and transfer loading of the buckets. Overloading the buckets causes spillage and can increase kernel breakage.

Loading grain on the up side of the leg causes more damage than loading on the down side (20), which should be a consideration for elevators handling corn. For wheat, no difference can be detected as long as the leg is operated at normal speed.

Belt conveyors are the primary means of moving grain horizontally in most commercial facilities and, as mentioned, are becoming increasing popular for vertical lifting. They consist of an endless belt supported by rollers and driven by a shaft-mounted speed reducer motor. They are usually open, but may be covered when used outside a building. Belt width varies and can be operated at 500 to 550 feet per minute. Conveyors can be inclined up to 15°, but should be horizontal at the point of loading. They can accommodate a wide range of speed or volume demands, are energy-efficient, and have relatively low maintenance and operating costs. Grain breakage is minimal when moved this way. Most belt conveyors are used in fixed installations, but portable inclined models are available for use in loading flat storages.

Other types of conveying equipment include drag flight, screw auger, and pneumatic conveyors. Drag flight conveyors are enclosed tubes in which a chain with paddles or flights moves. The chain is driven by a shaft and sprocket in the head discharge section with an idler shaft and sprocket in the tail section to maintain tension on the chain. As the flighting moves, it carries grain along with it.

Drag conveyors are available in a wide range of sizes and capacities and as fixed or portable models. They are relatively inexpensive, easy to load, move grain at low velocities, and require less space than conventional belt conveyors. Since they are enclosed, they are subject to higher levels of insect infestation than belt conveyors are, The demand for low-cost conveyors has resulted in a substantial increase in the use of drag conveyors.

Screw auger conveyors have for many years been the principal means of moving grain on farm or where inexpensive portable equipment is needed. They consist of a round tube with a continuous spiral or screw inside and can be powered by farm tractors or electric motors. They are space-efficient and portable, and can move grain horizontally or at relatively steep angles. On the negative side, they have high power requirements and can cause considerable grain breakage, depending on the design and operation of the auger.

Pneumatic conveying is a system that moves grain by air inside a pipe. The air-moving device must be able to provide the air velocity and sufficient pressure to overcome the airflow resistance and the resistance of the grain to flow through the system. Pneumatic system capacity is a function of conveyor size, power supplied, and the vertical or horizontal conveying distance. Pneumatic conveying normally requires more power than bucket legs. Factors that increase grain breakage include air velocities, poor pipe joint connections, and overloading the air-lock feeders. As with other handling equipment, breakage is not as great a concern for wheat as for corn. Pneumatic systems are not widely used in commercial facilities mainly because of the high energy input and power cost.

Storage Types

The most common and easily managed storage type is upright concrete or metal bins (32). Bin sizes can range from as little as 3,000 bushel farm bins to over 500,000 bushel bins at commercial facilities. Upright bins are generally filled from the top and unloaded from the bottom by gravity flow. Bins can be various heights, with deep concrete bins ranging from 98 to 164 feet. The bottoms can be flat or constructed with hoppers. Flat bin bottoms require the manual removal of grain left over after gravity flow has ceased. Most commercial bins have hopper bottoms that allow complete grain removal without assistance. Configurations can range from one or more individual farm bins to a multitude of bins tied together with handling equipment in commercial facilities.

Horizontal systems have long been used for extended storage. These buildings may be constructed of metal, wood, concrete, or any combination of these materials. Horizontal storages usually have flat floors and are filled from conveyors in the roof or by portable incline belts. The grain is removed by conveyor tunnels in the floor and manual movement with front-end loaders. Movement into and out of these buildings is very labor-intensive. Grain depth is lower in horizontal storage than in most upright commercial bins. Storing grain in large buildings creates additional problems in that the large roof area increases the risks of water leaks. These types of structures can stand alone or be tied in with upright bins in commercial facilities.

Grain can also be placed in piles directly on the ground or on pads and can be either covered (usually with a vinyl tarp that provides some protection from the elements) or left uncovered. Piles can be contained by fixed or movable sloping walls or circular rings. Any type of onground pile is difficult to load and unload and is very labor-intensive.

Quality Problems That Arise During Storage

Grain quality can be compromised by physical damage during handling and by biological agents (mold and insects) during storage. Grain damage during handling stems from breakage, which produces broken grains and fine materials, Storage problems increase when this happens, and damage from molds and insects is more likely to occur with higher amounts of these materials.

Insects create numerous problems in stored grain:

- economic losses because of the amount of grain consumed,
- wastes left behind in the grain,
- insect fragments in finished products, and
- grain heating,

Insects' metabolic processes can raise grain temperatures and moisture to ideal conditions for mold growth. In addition, another problem arises from the residues of pesticides used to control insects. (Insect control is covered in the next section of this chapter.)

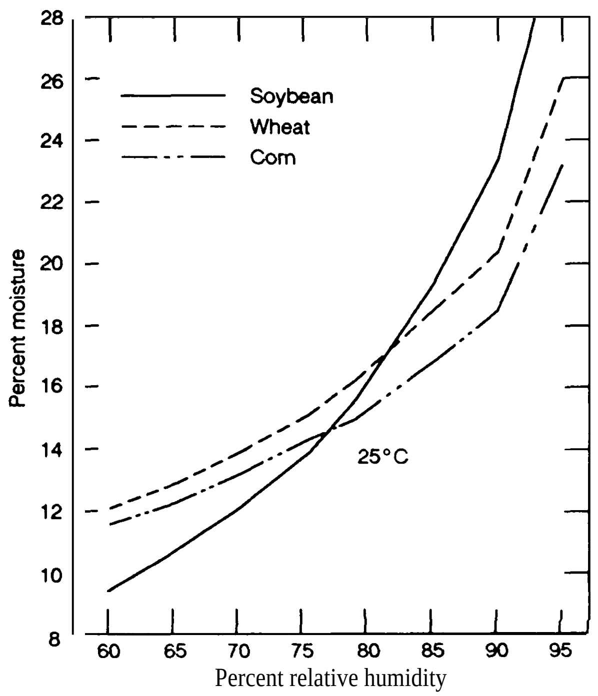
When molds grow they produce heat, moisture, and carbon dioxide. The heat and moisture provide even better growing conditions and the molds proliferate. Molds are parasites that obtain their sustenance from the grain they grow on. Grain quality is affected in that mold growth creates damaged kernels, deposits toxic substances, and creates a loss in dry matter, with accompanying decreases in density.

Interactions between moisture, temperature, and relative humidity spurs mold growth and increases insect activity. Basically, a grain moisture in equilibrium with 65 percent relative humidity will support mold activity. Different grains will create the optimum relative humidity at different moisture levels, which is why soybeans cannot be stored at the same moisture content as corn (figure 7-12).

Many fungi species can develop in stored grain and each has its own requirements for growth. *Aspergillus flavus* is a prime example in corn. This species produces aflatoxins when humidity is at 75 to 85 percent (15). Other species grow at lower humidities and temperatures, Fungi are more sensitive to moisture content than to temperature, with some species still active at near-freezing temperatures but high humidities.

Additional biochemical changes accompany damage from mold and insect invasion. A linear relationship has been established between free fatty acid content in soybeans and damage (38). In wheat, heating grain destroys glu-

Figure 7-12.-Moisture, Temperature, and Relative Humidity Interactions



SOURCE: Office of Technology Assessment, 1989 ten protein functionality. Damaged kernels may or may not reduce feed value per unit of weight; studies have reported varying results. Moldy kernels have a greater risk of containing one or more toxins.

Moisture weight is lost during routine aeration. Also, when grain spoils, it heats, and the heat liberated is capable of evaporating additional water. Investigations suggest that as damaged kernels increase, additional weight is lost. Kernel weight and density also reflect loss in dry matter. One study reported a 1 to 2 pound test weight loss in the entire grain mass from typical insect infestation (61).

Increases in damaged kernels and reductions in test weight are exponentially related to grain moisture and temperature (60). This research led to development of an Allowable Storage Time Table for corn (table 7-4). At the end of the Allowable Storage Time, corn will be on the verge of dropping one grade as defined by the U.S. Standards for Corn and will have lost about 0.5 percent of its original dry matter weight.

Neither grain temperature nor the moisture content of a spoiling mass remain constant over time (15). Other recent studies show that mold toxins can be produced before the Allowable Storage Time is reached. Extensive work to develop an Allowable Storage Time Table for wheat and soybeans has not been done. However, the basic principles are the same; the only differences would be the moisture content and number of days.

Storage Techniques That Protect Grain Quality

Controlling Breakage

Research has shown that breakage during handling is more significant in corn than in wheat and soybeans (43). Drop height in free-fall and spouting tests were found to be the most significant variables, with the largest amount of breakage occurring when dropping grain against a hard surface. Higher moisture content and temperatures are the best conditions for minimizing breakage, but these are not optimal for safe storage.

The National Grain and Feed Association has found that "repeated handlings showed that the amount of breakage was cumulative and remained constant each time grain was handled or dropped: This was found true whether or not the broken material was removed from the test lot before subsequent handling" (43). It also found that belt speed in bucket elevators has no measurable effect on grain damage, but grain thrower tests show breakage increased with increased belt speed. Tests for impacts showed slightly less breakage against wooden bulk heads than against steel ones. Grain breakage was also found to increase in screw conveyors not operated at full capacity. Three factors must be controlled to reduce the amount of breakage:

1. velocity,
2. repeated handlings, and
3. impact surface.

Table 7-4.—Allowable Storage Time for Corn

	Corn moisture (percent)						
Grain temperature (oF)	18	20	22	24	26	28	30
	days in storage						
30	648	321	190	127	94	74	61
35	432	214	126	85	62	49	40
40	288	142	84	56	41	32	27
45	192	95	56	37	27	21	18
50	128	63	37	25	18	14	12
55	85	42	25	16	12	9	8
60	56	28	17	11	8	7	5
65	42	21	13	8	6	5	4
70	31	16	9	6	5	4	3
75	23	12	7	5	4	3	2
80	17	9	5	4	3	2	2

SOURCE: Midwest Plan Service, "Low Temperature and Solar Grain Drying," Iowa State University, Ames, 1A, 1980.

Grain velocity is considered the most important factor to be controlled (table 7-5).

Monitoring Moisture Content

Molds will grow on any kernel or group of kernels that provide the right conditions. Moisture content and uniformity within storage facilities is therefore critical to maintaining grain quality. As demonstrated by the Allowable Storage Time Table for corn, knowledge of the moisture content is a key element in determining storability. Moisture uniformity within a storage facility, on the other hand, is subject to the limitations of measurement equipment and the ability to segregate differing moisture levels within the facility.

Moisture meter accuracy was discussed in the drying technologies section of this chapter. The meters provide average readings, but moisture levels within a grain sample can vary greatly. This can lead to false assumptions and hamper appropriate actions based on the average moisture reading, especially when handling nonuniformly dried corn that has been blended with high and low moisture levels and when handling freshly harvested corn. The problem is compounded by the fact that the moisture content of corn kernels on one ear can vary from 1 to 4 percent. Also, moisture will never fully equalize, If the spread from high to low is 4 percent, moisture will equalize within 1 percent (49). The net result is that moisture variation in a grain sample cannot be detected and the diversity of moisture being placed into storage cannot be controlled.

Nonuniform moisture levels in a storage facility can also be a function of the number and size of storages available. Segregating differing moisture levels in horizontal or pile storage is difficult, and several different moisture levels are often comingled. Large upright bins predominate in some corn- and soybean-producing areas. Depending on the number and size of bins available, and on the moisture levels being stored, differing moisture levels must be comingled.

Table 7-5.—Relative Amounts of Breakage for Grains Tested Under Four Handling Conditions

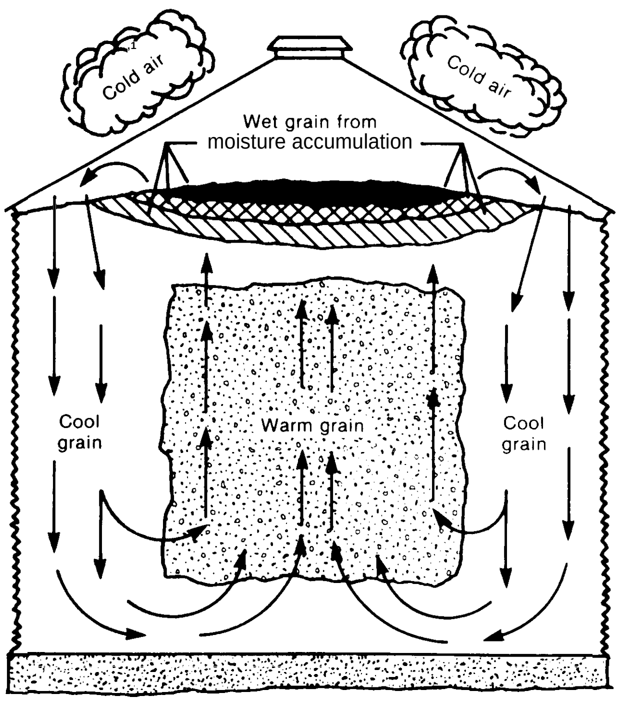
Grain	Percentage of grain breakage caused by: Free-fall drop	Spouting drop	Grain thrower	Bucket elevator
Corn ., ...	6.3	3.2	1.6	1.1
Soybean	2.0	1.0	0.7	0.3
Wheat	0.2	0.15	0.2	0.1

SOURCE: J E Maness,"Maintain Grain Quality Through Good Handling Practice, " National Grain and Feed Association, Washington, DC, 1976

Moisture content in any one particular location within a storage facility is subjected to the moisture/temperature/humidity relationship. Nonuniform moisture levels can lead to spoilage in localized areas within storage (14,17). These locations are commonly referred to as hot spots; if left unattended, they can spread to the entire grain mass.

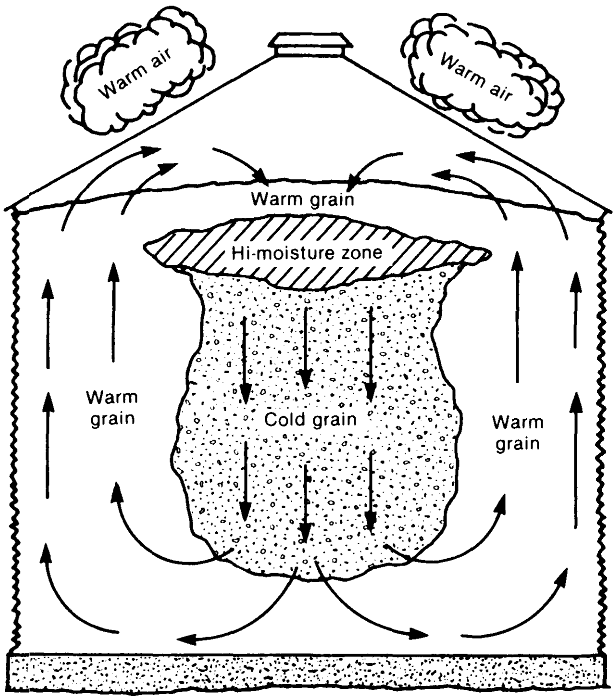
Even assuming that moisture and temperature are uniform within a grain mass, they will not remain so over time, as noted earlier. Moisture will migrate in response to temperature differentials (figures 7-13 and 7-14). When the

Figure 7-13.—Moisture Migration Patterns in Falling Temperatures



SOURCE G H Foster and J L Tuite. "Aeration and Stored Grain Management. " In *Storage of Cereal Grains and Their Products* (St Pau 1, M-N American Association of Cereal Chemists, 1982)

Figure 7-14.—Moisture Migration Patterns in Rising Temperatures



SOURCE G H Foster and J L Tuite, "Aeration and Stored Grain Manage-merit, " in Storage *of Cereal Grains and Their Products* (St. Paul, MN: American Association of Cereal Chemists, 1982)

outside air is warmer than the grain, the area of condensation is several feet under the grain surface, but still in the center.

This moisture migration during storage means that grain assumed to be in a storable condition will not remain so over time. Cold weather migration primarily affects grain in land-based storage, causing deterioration as temperatures rise in the spring. Warm weather migration is particularly vexing for grain in transit both from cold to warm areas of the United States and from the United States through warm waters to foreign buyers. A barge or ocean vessel is basically a storage bin and will experience the same moisture migration phenomena as land-based storage facilities. Although aeration is the tool for managing moisture migration, grain in transit cannot be aerated, and ventilating the top of barges or ocean vessels does little to remove moisture or heat.

Maintaining low temperatures and moisture levels in grain is the principal way to preserve grain quality and prevent damage from molds and insects. Aeration is a very effective tool for controlling moisture content and temperature. The rate of development for both molds and insects is greatly reduced as the temperature is lowered.

Aeration systems generally provide an airflow rate of 0.02 to 0.10 cubic feet per minute per bushel of grain. This is equivalent to 2 to 12 changes of air per hour. Aeration fans can be located at the base of a bin to create either a positive pressure pushing air up through the grain or a negative pressure by pulling air down through the bin. Some installations use fans mounted in the roof or bin top and some use fans, top and bottom, that pull and push the air.

Resistance to airflow increases with grain depth, so more power is required to aerate deep silo-type bins than shallow horizontal storage. Aerated bins and warehouses must have adequate ventilator area in the top to allow air to enter or exit when the fans are running.

The equipment and methods used to fill a storage bin affect the aeration system's performance. Dropping grain into the bin's center causes a cone to develop—with the lighter, less dense material concentrating in the center (spoutlines) while the heavier, denser material flows to the sides. This impedes airflow during aeration and molds can begin to grow almost immediately. In grains with relatively high amounts of fine material, such as corn, spoutlines are often removed from upright storage bins by drawing some of the grain out from the bottom, a practice called coring.

In large horizontal storages, loading from the center or from a loader that is gradually moved backward through the center of the building as the pile is formed causes similar problems. If grain is piled over each aeration duct on the floor by moving the loading device back and forth, airflow will be greatly increased. Airflow distribution is not as uniform as in upright bins, however. Some methods of filling piles also result in fine material concentrating in local areas. Piles, however, are difficult to aerate and their shape alone restricts uniform airflow.

Condensation in aeration ducts can be a problem when the fans are not running during warm weather and when the grain mass is cold. If outside air can enter the duct, moisture will condense there. Likewise, moisture from warm grain can condense on a cold aeration duct exposed to outside air, The accumulated moisture allows mold to grow, sometimes caking the grain around the perforated ducts, Air valves or tight-fitting covers should therefore be used to prevent air infiltration when the fans are not running.

Although aeration is primarily used for temperature control, grain moisture can be changed depending on the humidity, airflow rate, and length of aeration time, If wheat with 13 percent moisture is aerated with air at 40 percent relative humidity, there will be a gradual moisture loss from the grain. Humidities above 70 percent tend to add moisture to the grain. For this reason, coupled with the cost of operation, aeration systems are often run at the minimums considered necessary.

Many bins, especially on the farm, are equipped with aeration systems but are often not used effectively (27). Farm storage bins, especially smaller and older ones, often are not aerated. Small bins (holding less than 3,000 bushels) will cool or warm quickly enough with the changing season that moisture condensation may not be a serious problem. Farm bins that are aerated, on the other hand, are more likely to have systems improperly sized for the bin.

A majority of farm aeration systems are either not operated at all or not operated sufficiently (61). The most common problem is not running the fans long enough to bring the entire grain mass to a uniform temperature. If a cooling front is moved through only part of the grain, a moisture condensation problem is likely at the point where the warm and cold grain meet,

Temperature Monitoring

One way to monitor temperature is through the use of temperature cables. These can be hung from the roof or bin top and extend down through the grain mass. Each cable has a steel support cable and a number of thermocouple wires in a protective plastic shield. Cables can be placed in the bin before it is filled or can be probed into the grain, as is the case for horizontal storages and piles. As grain that is heating more than 1 or 2 feet from a thermocouple may not be detected until considerable damage is done in the hot spot, spacing and the extent to which detection is desired are critical.

Temperature increases that cannot be explained by changes in ambient conditions are a signal of possible mold or insect problems and should be investigated. Commercial facilities have relied on temperature monitoring systems for years, and many farmers also monitor grain temperatures.

Most temperature monitoring at commercial facilities is done on a fixed schedule either manually or by automatic recording equipment. A few facilities have installed programmable equipment that can be used in conjunction with aeration fan controllers. The system can be programmed to respond to higher temperatures by switching on an aeration fan. The cost of such systems has thus far limited their use to a few large companies,

Transfer Turning

Transfer turning is the process of physically moving grain from one storage bin to another, It is used primarily in upright storage facilities that have bins linked together by conveying equipment. The turning process mixes grain and contributes to a more uniform moisture and temperature. When hot spots are detected, the affected bin may be unloaded and transferred to another bin to break up the hot spots and allow the facility manager to identify and treat the cause. In facilities not equipped with aeration, turning has been the traditional means of grain cooling, It requires much more energy than aeration does, however, and can contribute to physical damage by breaking the kernel.

Turning grain cannot be performed in horizontal or pile storages because of the difficulty in unloading and moving the grain. To turn grain efficiently, a facility should have empty bins at its disposal that are connected by a conveying system. This is not the case on most farms. When bin space is limited, a bin can be unloaded and reloaded in one continuous operation.

Emerging Technologies

Little new technology is available in grain storage, but some technologies have been recently improved or applied. Programmable controllers for aeration systems are now available that monitor ambient temperature and humidity as well as grain temperature and that can be set up to run aeration fans. These will reduce management errors such as not moving a cooling front completely through the grain or aerating when weather conditions are unsuitable.

INSECT MANAGEMENT INTERVENTIONS

As indicated in the preceding section, insects create numerous economic and quality problems in stored grain. Losses due to insects worldwide range from 3 to 40 percent of the grain produced (44).

Preventing insect infestations should begin on the farm with an effort to clean grain and remove foreign material, (Cleaning technologies are discussed more fully later in this chapter.) A protective treatment, such as malathion, should be used if grain will be stored on farm. Beyond routine cleaning and spraying of empty storage facilities, few preventive treatments are applied to freshly harvested grain (7,61). These treatments are performed mostly on wheat, but sometimes on corn or soybeans. Also, protective treatments are used most frequently in the southernmost grain-producing States, where the climate is most favorable for insect activity.

As grain is marketed and moves from the farm through various facilities for export or domestic use, it is impractical to maintain the identity of a particular lot that has been treated, Thus, a treated lot may receive additional insecticides or fumigants as it moves through the marketing chain, This can result in adulteration of either the grain or the finished product with excessive pesticide residues.

In the absence of preventive treatment, infestations are controlled on a case-by-case basis as they occur. If grain is turned, a protective treatment may be applied. Exposed adult insects may be killed, but the immature ones inside the kernels will not be killed until they emerge as adults. Even when grain is fumigated, a 100-percent” kill may not be achieved. The population may be reduced to an undetectable level and several generations may pass before infestation is detected. In either case, numerous immature and even pre-emerging adult insects remain inside the grain kernels. Many are not removed by the preconditioning processes used in the milling process, and insect fragments can be found in finished products.

With present technology, pesticides are the only available and entirely satisfactory method of ridding grain of live insects. The use of other control measures is severely limited by the inability to penetrate grain depths, available time for application and kill, quantity to be treated, and the product cost (including labor).

Pest control in grain storage facilities and transportation vehicles is therefore economically driven, If it costs money it will in all likelihood not be undertaken unless not doing so would prohibit grain sales, Of course, this is true not only for the use of pesticides, but also for aeration, turning, cleaning, or other measures to control damage and/or prevent quality losses. Although this approach is an option in a free market, it can result in situations where buildup reaches such proportions that preventive approaches such as aeration, turning, and the application of residual pesticides no longer work, Emergency or corrective actions, such as the use of a fumigant, are then needed.

Current Pesticides

The pesticides used to control live insects can be divided into two broad categories: insecticides and fumigants. Insecticides are applied to facilities or directly to grain. The term "grain protestant" refers to the application of an insecticide to grain as it is conveyed into storage. The application is expected to provide a residue that will protect the grain from insects during storage. When properly applied, grain protestants should prevent or minimize additional damage caused by existing infestation and protect clean, uninfested grain from becoming infested. Insecticides labeled as grain protestants can also be applied to empty storage facilities, although these must be cleaned beforehand if the full value of the treatment is to be realized.

The term "fumigation" is often used incorrectly today. Many people believe that any application of fine insecticide particles into an enclosure or building as an aerosol, fog, mist, or smoke is to fumigate. But fumigation is a separate technology from other chemical control methods:

> . . . a fumigant is a chemical which, at a required temperature and pressure, can exist in the gaseous state in sufficient concentrations to be lethal to a given pest organism (9).

As this definition implies, fumigants act as a gas in the strictest sense of the word; they can penetrate into the material being treated and can then be removed by aeration. Fumigation, therefore, is a highly specialized art involving the application of some of the most toxic and unique pesticides. It requires professional personnel who are well trained and experienced regarding both the fumigant and the target organism.

Insect infestations usually involve a complex of insect species, and each species and life stage differs in its susceptibility to an insecticide or fumigant (22,26), The dosage must therefore be directed against the least susceptible life stage.

Grain Protectants

For many years, synergized pyrethrins were the only insecticides approved for use as a grain protestant, although none are approved for use on soybeans, Consequently, they have a long history of safe usage. Pyrethrins are both toxic and repellant to many species and have a rapid "knock down" effect. This does not mean the insects are dead; in fact, they may recover with no detrimental effect (42). Even though pyrethrins have been used for many years, insects have developed little resistance to them.

Several factors have limited the use of pyrethrins during the past 15 to 20 years. Pyrethrin extracts must be imported and, as such, the supply is not as reliable as desired. With the approval of malathion as a grain protestant, pyrethrins were no longer economically competitive. Also pyrethrins lacked the biological efficacy desired as a grain protestant (less than 100 percent kill of some species and life stages) that appeared more promising with malathion.

Malathion has been the insecticide of choice for more than 20 years, although it too has never been approved for use on soybeans, Convincing evidence of insect resistance to malathion was first reported in the mid-1960s, and during the last 15 years alarmingly high levels of resistance have been reported. Because there is no practical and economical alternative, malathion continues to be used even though its value as a grain protestant is doubtful in many cases (23).

Pirimiphos-methyl has been recently introduced. The commercial name for this product is Actellic. It controls a wide range of insect species, including those resistant to malathion. Pirimiphos-methyl was approved for use on export corn and wheat (but not on soybeans) in 1986. In 1987, it was approved for domestic corn use. It is approved for use on stored grain in 14 other countries (36).

Chlorpyrifos-methyl has also recently been introduced. The commercial name for this insecticide is Reldan 4E. It controls a wide range of insect species including those resistant to malathion. In 1986, it was approved for use on wheat but not on corn or soybeans. A dust formulation has been approved for use as a protectant for wheat and corn but not soybeans.

Bacillus thuringiensis (BT), a bacterium, is the only insect pathogen used as a grain protectant. To be effective, the spores must be ingested by the insect; however, only moth species of grain pests are controlled by BT. BT provides little or no control of grain beetles or weevils.

Inert dusts, such as silica aerosols, magnesium oxide, aluminum oxide, diatomaceous earth, and clays, have varying degrees of potential as grain protestants. In general they are slow-acting and kill insects mainly by an abrasive action that results in desiccation of the insect. They do not perform well in moist grain or in high temperatures. The disadvantages to using inert dusts may outweigh their value. These include environmental contamination, damage to machinery, increased fire risk, lung damage to workers, and reduced grade and/or test weight of grain. As such, relatively little use has been made of inert dusts in the United States (26).

Fumigants

A structure must be gastight for fumigation to be successful. The fumigant gas concentration must be maintained long enough to kill the least susceptible life stage of the insects involved. Most fumigation failures can be traced to inadequate gastightness of a storage facility; higher dosages will not compensate for such deficiencies (66).

An ideal fumigant should be:

1. highly toxic to all life stages of the target insect;
2. relatively nontoxic to humans and animals;
3. highly volatile, with good penetrating ability;
4. noncorrosive to metals;
5. nonflammable or explosive under practical conditions of usage;
6. nonreactive with the commodity (does not produce an adverse flavor, aroma, or residue);
7. nonharmful to seed germination;
8. economical, readily available, and simple to use;
9. fast acting, able to be aerated quickly, and nonharmful to the environment; and
10. easily detectable, with adequate warning properties.

Unfortunately, there is no ideal fumigant. However, the grain fumigants available possess some of these characteristics. Therefore, it is very important that fumigators be well informed on the performance characteristics of each fumigant so that a fumigation can be performed in a safe and effective manner. Two compounds—methyl bromide and hydrogen phosphide—are presently available as grain fumigants. Of these hydrogen phosphide is the fumigant of choice.

Methyl bromide is highly toxic to all life stages of grain insects and humans. Because it is essentially odorless, extreme care is necessary to avoid exposure. As methyl bromide is a liquid under pressure, it is highly volatile, but to achieve good grain penetration, forced recirculation is required. Methyl bromide gas is noncorrosive to metal, but the liquid phase reacts with aluminum in the absence of oxygen to forma compound that ignites spontaneously in the presence of oxygen. It is, however, neither flammable nor explosive under practical conditions of fumigation.

This fumigant reacts with most food commodities and grains to produce inorganic bromide residues that are permanent and accumulate with each additional fumigation. It also reacts with a host of other nonfood items, especially those that contain sulfur compounds. The degree of reaction is relative to the dosage applied, product temperature, duration of the fumigation period, and the number of times it is applied. When the inorganic bromide tolerance is exceeded, adverse flavor or aroma (or both) of the product may occur.

Methyl bromide is economically competitive with other fumigants and is readily available to authorized personnel. Using it requires special equipment both for application and safety, Because it is a liquid under pressure, knowledge and experience in using the equipment is essential. The need for recirculation substantially limits its use. Recirculation equipment is expensive and can only practically be used in facilities that are sufficiently gastight to prevent gas losses caused by the positive pressure of the system.

Fumigations can be completed within 16 to 24 hours, as methyl bromide is considered to be as fast acting as most fumigants. The recirculation system used during application can be used as an aid in aeration. Most of the unreacted methyl bromide can be aerated in 3 to 4 hours; however, atmospheric aeration should continue for 48 hours or more before moving the grain. As methyl bromide is practically odorless at low levels that are dangerous to humans, it lacks adequate warning properties.

Hydrogen phosphide will probably continue to be the fumigant of choice within the foreseeable future. It falls short of the ideal, but has many usable qualities not available in any other fumigant. It is highly toxic to all life stages and is very toxic to humans. Hydrogen phosphide is highly volatile with excellent penetrating quality. It is formulated as a solid either as aluminum or magnesium phosphide. Gas is released when the formulation is exposed to the atmospheric moisture. However, it is corrosive to certain metals such as copper, gold, and silver.

This fumigant can be highly flammable or even explosive under conditions of misuse, such as application resulting in extremely high concentrations of gas. It does not react with grain to cause either adverse flavor or aroma nor does it cause excessive residues. Hydrogen phosphide is economical, readily available, and the simplest fumigant to apply. A formulation can simply be scattered randomly, placed systematically on the grain surface, or submerged into the grain. Many methods have been developed to increase gas distribution in the grain mass. Hydrogen phosphide is not a fast-acting fumigant compared with methyl bromide, and it can take 3 to 5 days or longer depending on the temperature. Even longer periods are required when large masses are to be fumigated.

With cross-ventilation, hydrogen phosphide is removed from the free space in storage facilities within minutes. Low gas levels may continue to evolve from the grain, but with continued cross-ventilation, people can enter the facility and even work with the grain. Hydrogen phosphide is easily detected by use of detector tubes and contains an odor so it can be detected at very low levels, Although the odor can be a useful warning sign, it may not persist throughout the fumigation to therefore provide adequate warning during aeration.

Among the chemicals used as insecticides, fumigants are the finest tools available. Fumigation, however, is the last line of defense when all other insect control methods fail. Special care needs to be exercised to avoid any exceeding tolerances that may lead to cancellation by regulatory authorities or the loss of effectiveness due to development of insect resistance. Although the technology is available to accomplish 100 percent kills of the target insect, the diversity of storage facilities and conditions under which fumigation is performed means a 100 percent kill is seldom achieved.

Most fumigations are of a commercial or economic control type. This is accepted because most storage facilities are not sufficiently gastight to retain the fumigant, and the cost of securing gastightness maybe prohibitive. This type of fumigation is often accepted where very large grain masses are involved or when time is limited, such as in large elevators and export grain in shipholds. Although some of these facilities may be sufficiently gastight, the technology for achieving gas distribution throughout the grain mass has not been adequately researched and developed.

If there are enough insects to require fumigation, there are greater numbers of immature insects living inside individual grain kernels. Commercial or economic control fumigations often do not kill these immature insects. Though the grain may pass visual inspection for live adult insects, many of the immature insects develop and emerge as adults within the next 2 to 4 weeks and the grain is reinfested.

Two important problems arise from this type of fumigation. First, shipments certified as not being infested may arrive at their destination infested. Second, insects not killed by fumigation are exposed to sublethal dosages, which is the basis for developing resistance. Insect resistance to any of the fumigants means a major loss in this last line of defense.

Conditions Affecting Insect Management

The application and effectiveness of residual insecticides and fumigants may be seriously limited by the amount of time available, the space or volume of grain to be treated, the economics or dollar value saved or gained by their use, or legal restrictions on the use of various pesticides by local, State, or Federal authorities. The effectiveness of residual insecticides depends on the grain and storage facility being properly treated: The insect must come in contact with the residual before the pest will be killed. Similarly with fumigants, if there is not sufficient time for the gas to reach all parts of the grain mass in the required quantity and for the required duration, the pest will survive.

Types of Storage

The types and quality of grain storage facilities vary greatly, as noted earlier in this chapter. Farm storages have generally been suitable for fumigating with liquid fumigants (e.g., carbon tetrachloride, ethylene dibromide, ethylene dichloride, carbon disulfide, and chloropricrin) that were poured, sprinkled, or injected into the grain. These liquid fumigants are no longer available, and it is questionable whether some of these facilities can be sealed adequately and economically to retain fumigant gas such as hydrogen phosphide. In some cases, farmers may be advised to increase fumigant dosage to compensate for gas leakage. This will result in failures and can lead to insect resistance and ultimately the loss of the fumigant from the market.

For several reasons—such as remoteness of farm storage facilities, small amounts of grain to be treated, inadequate storage structures, and lack of information—much on-farm grain may never receive properly applied insect controls. When this infested grain is marketed, it comingles with noninfested grain and inflates the problem (7).

Although many high-quality on-farm storage facilities boast good pest management practices, the well-constructed facilities that utilize pest management technologies are generally found in commercial handling facilities that use upright silos (or bins) or horizontal (flat) storage. They are usually equipped with some type of forced aeration for cooling and drying. These systems are not designed for recirculation, which is required for fumigation with methyl bromide. Most horizontal or flat facilities are not adequately gastight for fumigation with either of the available compounds. Hydrogen phosphide can, however, be used when facilities are adequately gastight.

Most upright storage structures are gastight or can be made adequately gastight with a minimum of sealing. The ideal time to fumigate with hydrogen phosphide or apply an insecticidal protestant is when the grain is conveyed into storage. However, it is impractical to apply a fumigant at this time because the flow or supply of grain is irregular, and much of the harvest must be completed before the storage is filled. Thus, a great deal of the fumigant gas is lost as grain is added, The next best treatment opportunity is when turning grain from one full tank or silo to an empty one. This is not always done because empty storage space may not be available and it is expensive to turn grain. Sometimes grain is fumigated by probing or submerging fumigants into the grain surface. Most of these fumigations are only partially effective because sufficient time is not allocated to effect gas distribution.

Port Facilities

All port facilities have upright storage structures, although these are best described as handling, not storage, facilities. Any type of insect control remedy can cause expensive delays in loading. Because of the different types and grades of grain handled, even the largest port facility can seldom store enough grain for one shipment. Instead, enough grain is held to begin loading a ship, then a constant flow of grain from railcars and barges is unloaded into the facility and transferred directly onto the ship. Incoming grain that is infested can be set aside and fumigated before unloading, but grain found to be infested after loading on the ship is usually fumigated with hydrogen phosphide while in transit.

Transportation Modes

The time grain normally spends in various transportation modes—combines, trucks, railcars, and barges—is minimal. Yet these can be important sources of infestation. prolonged storage, especially in ocean vessels, is a unique situation that should be treated as storage rather than transportation.

To be effective, **a** fumigant **gas** must be distributed throughout the grain mass and held for the duration required to kill the insects involved. Few transportation modes are adequately constructed to retain fumigant gases. Those that may be sealed or made gastight include covered hopper railcars and hopper-type trucks, Other types of railcars, trucks, and even barges cannot be made gastight either at all or economically, Ocean vessels, on the other hand, have proved to be effective locales for fumigating grain in transit,

Outside Factors

Physical.—Many physical factors affect the performance of chemical interventions. Among these are temperature, moisture, and humidity. Temperature probably has the greatest impact. Usually within well-defined limits, an increase or decrease in temperature means a similar increase or decrease in the insecticide's performance, Temperature most dramatically affects the performance of fumigants, especially methyl bromide, High-moisture grain increases absorption of fumigants such as methyl bromide, requires higher dosages, and accelerates the breakdown of protective treatments such as malathion, The influence of humidity is varied, with minimal effect on the performance of most pesticides. However, hydrogen phosphide formulations require at least 25 percent relative humidity to cause the chemical reaction that releases the gas.

Foreign material and dockage covers a wide variety of items, but grain dust and other fine materials have the greatest effect on the performance of insect control interventions. When a protective treatment is applied, grain dust may absorb much of the insecticide, reducing its effectiveness. Likewise, concentrations of dust and fine material may require increased dosages of a fumigant to penetrate the grain mass. Dust **also** inhibits penetration of fumigant gases and causes the gas to channel so that penetration is slow or nonexistent in certain parts of the grain mass.

Human.—The competence of applicators is a major factor in the performance of any pest management intervention. An incompetent or inadequately trained applicator may apply too little or too much pesticide. The grain is either not protected or it may be contaminated with residues from high dosages, Inadequate training and experience are most likely on the farm, where pesticides are often applied by farmers themselves.

Biological. —Several biological factors must be taken into account for successful insect control. Some of the most important factors include the species and life stage of the insects involved, insect resistance to the insecticide, kind and condition of the grain to be treated, and the presence of beneficial organisms such as parasites and predators.

Infestation usually involves several insect species, and susceptibility to insecticides varies among species, life stages, and even the age of the insects within a species. Therefore, the insecticide or fumigant must be directed toward the least susceptible species and life stage. Several insect species are highly resistant to malathion and/or moderately resistant to synergized pyrethrins (69), and a few species have developed low levels of resistance to hydrogen phosphide (13).

Financial.—The cost involved should not be a deterrent to the timely and proper application of insect control. Studies indicate that materials cost less than 1 cent per bushel and that complete programs involving treating empty bins or warehouses average 2 cents per bushel (67). Other studies indicate that farmers do little to maintain quality during storage on the farm even though grain is discounted for live insects ***(7).***

Discounts assessed for live insects are quite variable. Discounts in Minnesota are reported as high as ***17*** cents per bushel for corn to 33 cents per bushel for wheat ***(27).*** A survey of commercial handling facilities across the Midwestern States reported discounts ranged from ***1*** to ***20*** cents per bushel (62). Obviously, the incentives to initiate and maintain insect control measures and deliver insect-free grain are either lacking or in question.

New and Emerging Technologies

The greatest potential for new residual-type pesticides may be in expanding the approved usage of the relatively new insecticides pirimiphos-methyl and chlorpyrifos-methyl. Both compounds appear promising as replacements for malathion. Both are effective against malathion-resistant insects, but are less than totally effective against the lesser grain borer, a major pest to stored grain. In Australia, mixtures of bioresemthrin, a synthetic pyrethroid, with chlorpyrifos-methyl have been shown to be effective. The use of insecticide mixtures has not received much attention in the United States because regulation requires safety data on all components as well as the mixture.

Several new approaches to insect control or prevention have been researched and brought to a usable point, but they have received little or no acceptance within the grain marketing system because of costs or predetermined performance limitations.

Modified atmosphere is a relatively new technology. Its basic performance needs are similar to those of a fumigant in that the facility must be gastight to retain a modified atmosphere of either nitrogen, carbon dioxide, or no oxygen for several days. The use of carbon dioxide appears to have the greatest potential,

Regardless of whether nitrogen or carbon dioxide is applied or an exothermic burner and condenser is used to create a low oxygen atmosphere, the logistics of providing large quantities of these substances or the initial cost and maintenance of the burner system will hinder implementation.

Hermetic storage involves total sealing, after a facility is completely filled, to exclude oxygen. Then, during long-term storage, the natural respiration of the grain and insects will deplete the oxygen and create an atmosphere lethal to the insects.

Much research has been completed on using irradiation to kill or sterilize insects and to disinfect grain. Recent studies indicate that the electron acceleration method of irradiation is the most practical and may be the most economical. Adoption of irradiation has been limited because of the high initial cost of installation. Installing an accelerator capable of treating ***1,000*** tons of grain per hour would cost some *$4* million (10). By operating the unit two shifts per day, 6 days a week, the maximum annual throughput would be 5 million tons. With this throughput and taking into account all foreseeable operating costs, treatment would cost about 23 cents per ton.

At a temperature of 16 °C or lower, insect activity ceases. Little or no feeding or reproduction occurs, but many insects will survive long periods at these temperatures, At temperatures near freezing, it requires 10 days or more to actually kill some species. Obviously the technology is available to modify temperatures to maintain quality of certain high-value agricultural products, However, it would be economically impractical to freeze large grain masses by mechanical refrigeration. Where climate provides naturally cold temperatures, aeration systems in storage facilities are used to reduce grain temperature to achieve insect control.

High temperatures can also kill insects. Studies using high temperatures concluded that microwave and infrared radiation can heat grain in thin layers, such as found on conveyor belts, to disinfest it (39).

TRANSPORTATION

The U.S. grain transportation and distribution system is probably the most efficient one in the world (8), Much of this efficiency was achieved during the 1970s when demand for export grain placed enormous stress on the system. Improvements made then resulted in high-speed, low-cost transportation and grain distribution. It is estimated that the United States is now capable of exporting over 8 billion bushels of grain per year, whereas in the mid to late 1970s the system was under great stress to export 3.5 billion to 5,0 billion bushels.

Current Modes of Transport

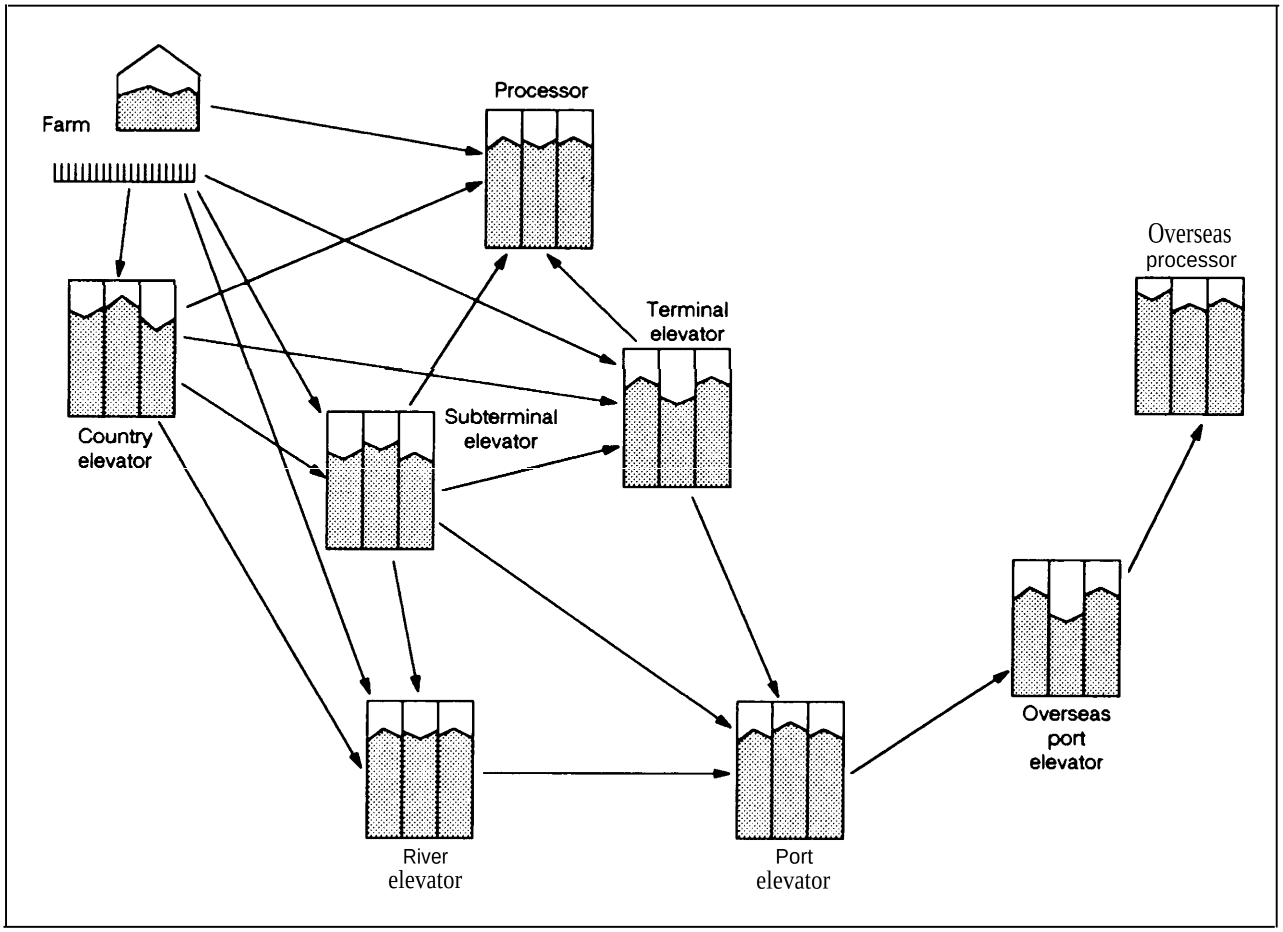
Grain may be moved from farms to country elevators or to inland terminal elevators, or directly to domestic end users (figure 7-15). Domestic users may obtain grain directly from farms or from country, subterminal, or terminal elevators by truck or train. Grain for export can be shipped from these elevators directly by rail, by truck to barge, or by rail to barge to export elevators in major U.S. ports for loading onto ocean-going vessels. Some farmers close to export elevators bring grain directly to these facilities by truck. Grain is also shipped by rail from subterminal or inland terminal elevators to Mexico, and small amounts of wheat and corn move directly into Canada by truck. Thus, the major carriers of grain are trucks, trains, barges, and ocean vessels.

Accurate measurement of the share of grain hauled by each mode of transportation is difficult since no agency collects data on grain shipments by truck. Also, more than one transportation mode may be used to move grain from a country elevator to the final user. Information on the total quantities of grain moved by rail and barge is available (table 7-6). The share of transportation by train ranged from a high of 80 percent in 1974 to a low of 66 percent in 1982. Barge shares tend to rise and fall as exports increase or decrease, primarily because most grain moving by barge is destined for export. The share of grain moving to export by rail declined from 62 percent in 1974-75 to 38 percent in 1983-84, while the share by barge increased from 37 to 60 percent (3).

By Rail

Trains have been the major carrier since the late 1830s, and single boxcar shipments remained the dominant grain transportation technology until the late 1960s. The use of boxcars, however, resulted in grain damage. The grain was loaded through a center door using flexible pipes that direct the grain flow into either end of the boxcar. Grain throwers were also used to assist in this process. Once loaded, the grain was leveled by hand. Since boxcars had no unloading devices, unloading involved an electric shovel that was dragged or pulled by

Figure 7-15.-General Flow of Grain From the Farm Through the System



SOURCE: U S Department of Agriculture, Office of Transportation, "The Physical Distribution System for Gram," Agriculture Information Bulletin No 457, Washington, DC, October 1983

Table 7-6.—Grain Hauled by Railroads and Barges, 1974-1985

	Billions of bushels moved by		Percent moved by	
Year	Rail	Barge	Rail	Barge
1974	4.21	1.03	80.3	19.7
1975	4.06	1.20	77.3	22.7
1976	4.10	1.61	71.8	28.2
1977	3.91	1.52	72.0	28.0
1978	4.12	1.63	71.7	28.3
1979	4.41	1.62	73.1	26.9
1980	5.00	1.91	72.4	27.6
1981	4.38	1.99	68.8	31.2
1982	4.22	2.18	66.0	34.0
1983	4.72	2.11	69.1	30.9
1984	4.81	1.97	70.9	29.1
1985	3.99	1.67	70.5	29.5

SOURCE Association of American Railroads, The *Grain Book 1986* (Washington, DC 1987)

a cable to the center door, using an electric motor. Unloading devices were designed to lift and tip the entire car in either direction so the grain would flow out the center doors. The whole process of transporting by boxcar was labor-intensive and damaging to the grain.

Boxcars were also a ready source of insect infestation since they have an inside wood wall liner. Frequently these were damaged, and bulk material, including grain from previous shipments, became lodged behind the liners. This material was for all practical purposes impossible to remove and, therefore, became infested and contaminated the next cargo.

The advent of the covered hopper car in the mid-1960s greatly reduced the loading and unloading stress on grain quality. Covered hopper cars have full-length top hatchways for relatively easy loading that does not require throwing or leveling. Each car consists of three to four smooth, hopper bottom compartments. Since grain is unloaded by gravity flow, each compartment is essentially self-cleaning, reducing the risk of insect infestation in the next shipment. The covered hopper car is tight and essentially leak-proof, making it easier to fumigate than boxcars. Moreover, loading and unloading is less labor-intensive and damaging to grain. By 1985, 99.6 percent of all grain transported by rail moved in covered hopper cars.

Until the mid-1960s, almost all grain transported by rail moved under single-car transit rates, This means that grain was shipped to a transit location (an elevator), unloaded for storage, and later reloaded and shipped to its final destination, The transit rate was usually lower than the inbound rate to a location plus the outbound rate to the final destination. In the mid-1960s, however, rail companies began offering low-cost, multiple-car and unit-train rates from country elevators direct to final destination, thus eliminating the stopover at transit locations.

Unit trains are a group of railcars shipped from one origin to one destination on one bill of lading and consist of 50 or more railcars. The unit-train concept eliminated the need to stop at numerous elevators to pick up cars for switching into a train. Turnaround time from the country elevator was much faster for unit trains than for single-car shipments. Thus, unit trains lowered costs of switching, fuel, and crews, and enabled companies to haul more grain with existing fleets. A portion of these savings were passed onto shippers in the form of lower rates, which enabled rail companies to be more competitive,

By the mid-1970s, multiple-car and unit-train shipments became the standard method for transporting corn and soybeans by rail. This shift to large direct rail shipments reduced not only grain transportation costs but also grain damage by eliminating unloading and reloading at transit elevators.

While the single-car transit system has been virtually nonexistent in the corn and soybean market since the mid-1970s, it continues to perform a major function in wheat distribution, particularly in areas producing Hard Red Winter wheat. More than half the wheat transported by rail from Kansas, Oklahoma, and Texas moves under transit rates. In part, this is because a large percentage of the grain storage capacity in these areas is located at inland terminals. In contrast, most storage capacity in the Corn Belt and the wheat-producing areas in the Northern Plains States is located at country elevators, and multiple-car and unit-train shipments are now standard. In addition, aggregating large quantities of wheat at inland terminals permits blending of Hard Red Winter wheat to meet export standards. Only a small number of country elevators in these areas are capable of blending wheat to meet export specifications.

By Barge

Most grain moving by barge originates on the Mississippi River system, which includes the Illinois and Ohio rivers. These rivers became navigable when a system of locks and dams made the entire river system navigable at 9-foot drafts in the 1930s. The major export locations served by barges are the Mississippi River elevators in New Orleans and the Pacific Northwest ports that are served by the Columbia and Snake rivers.

All grain moving by barge must be transported by truck or rail to barge-loading facilities, unloaded, and then reloaded into the barge. Barge tows, consisting of 12 to 30 barges pushed by a towboat, make the trip from barge loading facilities on the upper Mississippi to export elevators in New Orleans in 15 to 25 days.

Barges are not self-unloading, so unloading causes more grain damage than unloading hopper-type railcars. Typically barges are unloaded by lowering into the barge a marine leg or vertical belt with large buckets attached to scoop up the grain, When a barge is partially unloaded, a small crawler tractor with a front-end blade is lowered into the barge to push the remaining grain to the marine leg to complete unloading.

The major advantages of barges over railcars are the large carrying capacity of barge tows and the relatively low rates charged to transport grain to deep water ports in New Orleans. Table 7-7 shows the range of rail and rail-to-barge rates for grain shipped from central Iowa to New Orleans. Rail rates decline as the size of the shipment increases in both situations, but are still higher than for barge shipments.

Barge rates respond to supply and demand. During the 1970s, barge rates fluctuated between 100 and 200 percent of the Merchants Exchange of St. Louis trading benchmarks. Even with barge rates at 200 percent of tariff, however, the combined rail-to-barge rates are sharply lower than rates on rail direct to New Orleans. The rail rate advantage only increases with origins located closer to New Orleans.

Other advantages of barge movements are that they can be used as an extension to the export elevator for storage and that barges can be marshaled and unloaded in the New Orleans area. Many export elevators in New Orleans are high-speed transfer facilities with limited storage that are equipped to unload barges rapidly, usually one per hour. These elevators would be hard-pressed to unload the equivalent amount of grain from railcars in an hour and still maintain low-cost, high put through rates. Barges with specific qualities and quantities being stored on the river are controlled by the grain companies in the New Orleans area. These can be collected and moved to the elevator based on quality demands of a particular shipment at specific times desired. Unloading railcars means extra work in dealing with individual smaller units and storing specific quantities in the facility. Also, switching railcars into the facility and removing empty cars is subject to the availability of train crews. This places the facility at the mercy of the rail companies regarding delivery schedules when an entire export shipment is not in the facility.

Table 7-7.—Comparison of Rail and Rail. Barge Rates From Jefferson, Iowa, to New Orleans in Dollars Per Ton

Mode	Size of shipment	Rail direct to New Orleans	Rail to Clinton, 1A, barge to New Orleans
Rail	25-car	$25.40	$7.20
	50-car	23.60	6.60
	75-car	21.40	6.00
Barge at 100°/0 of tariff			5.32
Barge at 200°/0 of tariff			10.64

SOURCE: C.P. Baumel, “Alternative Grain Transportation and Distribution Technologies and Their Impacts on Grain Quality, ” background paper prepared for the Office of Technology Assessment, U S. Congress, Washington, DC, 1988.

By Ocean Vessei

In the 1960s, the Public Law 480 program dominated grain exports. A substantial portion of these exports were shipped in small (10,000 to 15,000 ton) vessels. Many of these were multipurpose vessels (’tween deckers) with several decks and small holds. Loading often caused grain damage. To provide cargo and vessel stability and to obtain full utilization of capacity, these vessels had to be trimmed, which involved throwing the grain under ledges and into corners of small holds, causing more grain damage. These vessels were difficult to unload and fumigate for the same reasons.

During the 1970s world prosperity increased cash export sales substantially. Importers and exporters shifted a high percentage of their shipments to larger vessels (50,000 tons or more) to gain lower per-ton shipping costs. These vessels are relatively easy to load and unload because of their large open holds with rolltop hatches and smooth sides, and thus create less grain damage than the “tween deckers.”

Grain can also be transported in tankers that are used primarily to ship oil. Loading tankers can damage grain, especially corn, because it must be loaded through a small opening, just big enough for a person to enter, in the middle of each hold. In each opening there is a permanently affixed ladder. As grain is loaded, it bounces off the ladder, causing increased breakage. Also, holds must be filled through very small openings at the corners to increase the hold’s capacity. Based on the location of these openings, grain may have to be thrown and diverted into the opening. Unloading tankers is more difficult and causes additional grain damage because pneumatic unloaders are required.

Quality Problems That Arise During Transport

The grain transportation and distribution system aims to move grain from the farmer to its final destination at minimum cost, subject to maintaining a specified level of grain quality. As figure 7-15 indicated, a large number of routes are available. Assuming a minimum of two handlings (one in and one out) at each location, grain might be handled six to eight times when moving through this system. This figure does not include the number of times grain is handled on the farm or within facilities. Thus, the relationship between the transportation and distribution systems affects grain quality. Changes in one system will require changes in the other.

The grain distribution system, as currently organized, has large investments in duplicate and out-of-location facilities, which tends to increase the number of handlings. The abandonment of a large number of branch rail lines during the 1970s left many country elevators without rail service. Most of these facilities, however, are still in operation. A substantial portion of grain received at these locations must be trucked to another facility that unloads, stores, and reloads the grain into railcars. At least two handlings could be avoided if farmers delivered grain directly to facilities with rail service. In effect, the facilities on abandoned rail lines recreate the transit system for corn and soybeans that caused additional breakage due to increased handlings. (This is not as important for wheat, which is less affected by extra handling.)

Other than increased breakage during loading and unloading, grain quality deteriorates in shipment in much the same manner as it deteriorates during storage. The negative impacts on grain quality presented in the storage section of this chapter regarding moisture uniformity and migration, temperature and humidity, insect invasion, and mold development also apply during shipment. This is because grain is in fact being stored while in transit,

Several factors peculiar to grain transportation must be noted, however. The areas discussed in the storage section as they pertain to solutions or preventive measures are not applicable to grain during shipment. For example, no mode of transportation is equipped with aeration, nor can grain temperatures and corrective actions be taken during shipment. Therefore, moisture uniformity is critical to maintaining quality. Moisture migration can be more dramatic during shipment since grain can undergo several outside air temperature and humidity changes. This is especially true when grain is loaded in a cold climate and moved through warm water rather quickly to a warm, humid climate.

Barge shipments appear to be more susceptible than railcars to these influences, since more time is spent in transit. One explanation is that railcars are more uniformly loaded than barges in terms of moisture, as barge-loading facilities have fewer bins for segregating different moisture levels. Also, barges are primarily used to transport corn and soybeans, with moisture and damage at higher levels than in wheat. Once grain is loaded into the mode of transportation that will carry it to its destination, maintaining grain quality is out of human control.

Grain travels up to 2,000 to 3,000 miles from the major grain-producing regions in the United States to ports. In the case of barge shipments, up to 3 weeks might be spent in less-than-optimum storage conditions. Spoilage in barge shipments to New Orleans have been found due to high moisture levels in portions of the barges. This happened in less than 3 weeks. Vessels used to transport grain to foreign buyers can take up to 50 days, not including port delays for unloading. This time increases the potential for grain spoilage and has been the focus of several studies on grain quality and the basis for many foreign complaints.

As discussed previously, as bulk grain is loaded, fine materials tend to accumulate in the center while the larger material tends to roll to the sides. The impact that concentrations of fine materials (spoutlines) have on grain quality can be minimized to some degree by moving the loading spout around so those materials do not concentrate in one spot. This cannot be done in tankers. But no degree of spout movement can completely eliminate the segregation of material in the hold of a vessel.

This creates some unusual problems beyond the effect fine materials have on quality. As vessels have gotten larger (for the reasons previously discussed), foreign buyers are receiving quantities that must be divided for distribution to the ultimate users. Many times the entire cargo is not reblended before being divided and distributed. This results in some users receiving higher quality (as defined by the average amount of fine material reported for the entire shipment) and some receiving poorer quality, even though the entire cargo was within specification.

Transport Techniques That Protect Grain Quality

Identity Preservation Within Ship Holds

One of the problems associated with large bulk shipments is the nonuniform nature in a ship hold of the grain that will ultimately be distributed to several users. One way to overcome this problem is to place a layer of burlap or plastic cloth and plywood between individual portions. Some countries specify that individual portions destined for specific users be separated in this manner.

Direct Transfer

One method for reducing the number of grain handlings is to transfer grain directly from one mode of transportation to another without unloading it into an elevator. For transfer from a railcar or truck to a barge, direct transfer could involve unloading the railcar or truck into a pit and transferring the grain by belt directly into a barge, thus eliminating the elevator handling. This method is currently being used in some locations.

Direct transfer from a barge to an ocean vessel can be accomplished with conventional unloading methods, marine legs, and movement by belt to the ocean vessel. A second method involves floating rigs. Currently, nine floating rigs in the New Orleans area perform this service. The cost, however, of direct transfer using floating rigs is higher than moving grain through export elevators,

Bagging

Export bagging facilities are currently in place at export elevators in Corpus Christi and Houston, TX, as well as in Pascagoula, MS. The bagging operation consists of placing grain into bags, sewing the bag shut, placing it on a pallet, and transferring the full pallet to a warehouse on the dock for loading to a vessel.

Most of the export bagging is currently being performed for Public Law 480 shipments of 1,000 to 4,000 tons per order. The cost is substantially higher: Bagging, including moving full pallets to a warehouse and then loading them, costs about $27.30 per metric ton compared with less than $1.00 for loading bulk grain (8). Bagging grain at country or inland elevators and shipping the bags to a port for loading would decrease the number of handlings.

Containers

Since the mid-1970s, most of the manufactured U.S. imports have been shipped in 20- and 40-foot containers. A large share of these return empty to Japan, South Korea, and Taiwan. Special high-quality grains such as seeds and soybeans for human consumption have been exported in these containers. However, little or no commercial-grade grains have been shipped in containers.

The cost of shipping containerized grain is significantly higher than any of the current bulk shipping technologies. One recent attempt to ship corn from Iowa in containers cost twice as much as the least-cost bulk handling rate. Grain loaded into containers at interior locations could be shipped overseas, thus reducing a significant number of handlings (8).

Identity-Preserved Shipments

The basic concept behind identity preservation is that individual grain shipments should not be comingled with others. Thus, the grain shipped from a specific location in the United States is the exact grain that the final user receives. Any of the previously mentioned modifications can be used for identity-preserved shipments. The associated costs are therefore related to the type of transportation mode selected. Much discussion has taken place on the merits of this concept, and several shipments have originated from interior locations for delivery to importing countries with their identities preserved.

Emerging Technologies

Only two new transportation technologies could help preserve grain quality: capsule pipelines and long-distance belts. The pipeline technology would move grain in capsules propelled by air pressure, Long-distance belts would carry the grain gently from one point to another.

Recent studies on the economic feasibility of capsule pipelines indicate that distance and quantity carried are the major determinants of the economic feasibility. The pipelines are cheaper than unit trains on shipments less than ***300*** miles and quantities in the range of **70** million to **80** million tons per year ***(8).*** The short distances mean that shipments would be limited to river terminals for loading onto barges for shipment to a port.

Large volume requirements are unlikely to be available to any inland shipping elevator unless the grain is trucked or railed to the pipeline loading elevator. This would raise costs and number of handlings. Once grain is loaded into a truck or railcar, usually the least cost method of transportation is to haul it directly to its destination.

The final remaining possibility for pipelines or belts is to transfer grain very short distances from large elevators to nearby export elevators or from export elevators to ocean vessels unable to reach the elevator because of shallow water, The widespread distribution of grain supplies in the United States effectively rules out the use of these technologies for moving grain from country elevators.

CLEANING AND BLENDING TECHNOLOGIES

Cleaning and blending are operations at the heart of many grain quality controversies. The purpose of cleaning is to remove material other than grain, shriveled kernels, and broken pieces of kernels. Blending is the mixing of two or more grain lots to establish a quality different from either lot. Blending is performed by exporters, individual elevator managers, and producers to assure uniformity and increase profits (33). Concerns over cleaning and blending initiated the Grain Quality Improvement Act of ***1986.*** In essence, many people believed that there was something inherently wrong about reintroducing material that had been removed from the grain. The act prohibits: 1) recombining or adding dockage, dust, or foreign material to any grain at export facilities; 2) blending different kinds of grain; and 3) adding broken kernels from one grain to another.

Cleaning

Cleaning wheat in commercial handling facilities is normally limited to removing dockage, insects, and to a limited degree shrunken and broken kernels. In corn, cleaning regulates the amount of broken kernels and foreign material; in soybeans, it controls the amount of foreign material and split soybeans. The handling and harvest properties of each grain, along with the location of grain cleaners, dictate the amount of cleaning required to meet various contract specifications. For example, corn harvested at low levels of broken corn and foreign material but high moisture must be dried and, due to its inherent nature, it breaks up during each handling.

Thus, cleaning corn to remove broken corn and foreign material is required at each handling in order to meet contract specifications and avoid discounts. As most dockage in wheat is generated during harvest, and as normal handling does not cause significant dockage increases, cleaning is not required each time wheat is handled. Soybeans, on the other hand, fall somewhere in between regarding breakage susceptibility and the amount of cleaning required at each handling.

Data are not available on the number of cleaners on v. off farms. The number on farms is probably related to the particular crop, the amount of on-farm storage, and the number of operations performed on the crop at the farm level. For example, most corn is stored and dried on farm. In wheat, on the other hand, drying is not required and the amount of dockage can be regulated by the combine. Therefore, significantly fewer cleaners are probably found on wheat then on corn farms.

Principles of Cleaning

The most common types of cleaners are mechanical screening and scalping devices. Scalpers remove material larger than grain and allow the grain and fine material to pass through. Smaller screens are used to retain the grain and allow small material to pass through. Screens may be stationary, with grain flowing or being swept along them, or they may be shaken or rotated. Cleaning grain using screen and scalping devices makes a particle size separation. Screen sizes vary by commodity, but usually coincide with the sieve sizes used in each Official U.S. Standard for Grain to define the respective factors.

Other types of cleaning devices use aspiration. This separates grain from less dense material by drawing air over a falling grain stream and pulling the lighter material into a cyclone-type separator. In addition to removing fine material, aspiration has also been found to be effective in removing insects from wheat. Cleaners using gravity tables (seed weight separation) and length graders (seed size separation) are used by seed conditioning plants. Screens and aspirators, however, are the only methods with the throughput capacity needed for modern bulk handling facilities.

The Official U.S. Grain Standards for corn and soybeans use particle size to discriminate between whole and broken kernels and foreign material. In wheat, particle size separations and aspiration are used to separate all matter other than wheat. This process does not distinguish between whole or broken kernels. The scalping process removes material considered to be foreign to grain (i.e., stems, chaff, cobs, etc.) and also does not distinguish between whole or broken grains. Screening removes smaller foreign matter, dirt, weed seeds, etc., but depending on screen size can also separate whole, broken, or split grains.

When establishing screen sizes, the relationship between removing unwanted foreign material and removing broken, split, or shriveled grains is important. Whenever grain is cleaned by screening to remove foreign material, screen size has an impact on the amount of broken or shriveled grains that will ultimately pass through, but no matter what screen size is established, screens cannot remove everything. For corn, the common screen size is a 12/64-inch round-hole sieve. This size has recently caused much discussion since it removes a large percentage of broken kernels. It is generally agreed that scalpers remove unwanted foreign material, but much debate has centered on the value of the broken grain removed at the same time. Since cleaning is intended to remove material that is lower in value than the remaining grain, setting screen size, especially in corn, is a balance between separating material that may have value from material that is of no value and that may cause quality deterioration.

A more recent discussion on setting screen size centers on the particle sizes that form spoutlines. Recent studies have shown that crevices between kernels act like a screen. Fine particles small enough to fall into these crevices form spoutlines. One study found larger particles in corn spoutlines than in soybean spoutlines, and that spoutlines essentially do not exist in wheat. It concluded that the best screen sizes for corn and soybeans would be ones that will remove all particles of a size to form spoutlines.

Aspiration, which is predominantly used to clean wheat and in some areas has been used to remove insect infestations, has been effective in removing the lighter, less dense material normally considered to be of no value. The problems associated with the percent and value of broken and shriveled kernels removed, therefore, would appear to be less. However, density decreases with particle size (31,68), and aspiration cleaning will produce cleanings of lower density than screen cleaning for the same percentage of material removed. One study found that low-density whole corn kernels are not of inferior feed value (28), but more recent studies show that they are a detriment to milling operations (53).

Another study measured the nutritive value of various corn particle sizes (30) (table 7-8). No particle size discriminated by nutrient content, nor was nutrient content. dramatically reduced with decreasing particle size. On the other hand, the majority of the dust and inert material was concentrated in the sizes 8/64 inch and below, while weed seeds were mostly between the 10/64 and 6/64 size.

The relationship between screen size and the value of the material removed is further complicated by the fact that smaller particle sizes contain less available starch to support mold growth (30), However, studies have also shown that concentrations of broken and fine material are conducive to insect growth and reduce airflow during aeration. Broken corn between the 16/64 and 8/64 sieves has been found to be more biologically active than the sieve sizes currently being considered for inclusion in the Official Standards for Corn (8/64 and 6/64) (30). The debate continues, therefore, on what should be removed and how much, and the material's relationship to setting grade limits and its effect on storability.

Current Procedures

Cleaners in commercial facilities are normally placed after the final elevation, Cleaning, therefore, is performed during loadout unless the grain is being cleaned to enhance dryer performance or is going into storage. On-farm cleaning, when done, is primarily to improve dryer performance.

Introducing clean grain to the dryer has the following advantages: 1) it results in more uniform airflow in the dryer and thus a more uniform moisture content of the dried grain, 2) it decreases the static pressure (airflow resistance) of the grain, thus increasing the airflow rate and dryer capacity, 3) it eliminates the drying of material that deleteriously affects final grain quality, and 4) it results in less air pollution (55),

Obviously, cleaning before drying also has some disadvantages. It requires additional investments in cleaners, the handling of wet broken corn and fine material, and the rapid sale of wet, easily molding material: it also results in some dry matter loss. Although the advantages of precleaning wet grain are fairly well understood by dryer operators, most do not do it. The quality of U.S. grain would improve substantially if precleaning was adopted (21).

Commercial cleaning requires high flow rates. Gravity or vibrator screen cleaners with

Table 7-8.— Nutritive Value of Corn Fines, by Particle Size

Property	Whole corn	Size range, 64th-inch					
		15-12	12-10	10-8	8-6	6-4.5	<4.5
Protein, percent dry basis	10.20	10.06	10.35	10.38	10.44	10.97	12.27
Oil, percent dry basis	4,47	3.86	4.25	3.40	2.48	2.43	2.43
Fiber, percent dry basis	2,24	2.34	2.64	2.85	3.51	4.24	5.91
Digestible energy, Kcal/lb.	1,785.80	NA	1,717.30	1,691.50	1,660.50	1,631.90	1,610.80

NA = not available.

SOURCE L D Hill et al , Changes in Quality of Corn and Soybeans Between the United States and England Special Publication No 63 Agricultural Experiment Station, University of Illinois, Urbana, IL, 1981 capacities up to 40,000 bushels per hour are the norm. The general configurations of cleaning systems are found in commercial facilities. First, the entire grain stream can be passed through the cleaner, with the throughput adjusted to produce the desired amount of material in the cleaned product. Alternatively, the grain stream can be overcleaned and the clean out metered back as required.

Second, the entire grain stream can be cleaned using a screen larger than the size required. The cleanings can either be recleaned to remove smaller material or reintroduced directly. This option is particularly useful when handling both corn and soybeans because it allows the facility to use corn screens, thus reducing the time and costs associated with changing screens. Third, the grain stream may be divided so that only part is cleaned and part left uncleaned,

All these designs are useful only if part or all of the grain exceeds desired levels. This may not occur at the first point of sale. Studies on handling breakage indicate that for corn, about 0.5 percent broken corn and foreign material, as defined by a 12/64-inch round-hole sieve, is created at each handling. This percentage could be higher or lower, depending on the particular handling facility and the drying method. Breakage susceptibility in wheat is far less.

Once inert material such as stems, pods, cobs, weed seeds, dirt, and chaff is cleaned out, no further cleaning is required. However, depending on the type of grain and its susceptibility to breakage, breakage will occur at each handling throughout the marketing chain. Thus corn and soybean cleaners are located throughout the marketing chain and in every export elevator, whereas wheat cleaners are located closer to the first point of sale and, except in a few instances, are not found at export elevators.

The amount of cleaning is dictated by the limits established by official grades, subsequent discounts for particular factors, and storability. For corn and soybeans, official grade limits are not normally exceeded at the first point of sale. As these commodities move through the marketing chain, however, they must be continually cleaned in order to meet grade limits.

Wheat dockage levels delivered by the farmer to the first point of sale are purchased, with dockage being deductible as a reduction from weight, Cleaning wheat to remove dockage at this point and throughout the marketing chain is therefore strictly a function of economics and, in many instances, quality is better regulated through blending instead.

In practice, four basic economic factors determine whether wheat should be cleaned or not:

1. the cost of cleaning,
2. the price of screenings,
3. dockage levels, and
4. the cost of transportation.

A 1987 publication by North Dakota State University reported on the results of its yearly survey of elevator operators in that State (16). Of 168 elevator managers surveyed, 159 indicated that wheat was cleaned prior to shipment. They also indicated that incoming harvest wheat was cleaned when dockage levels reached on average 2.6 percent. Wheat shipments exceeding the 2.6 percent average were cleaned down to an average 0.9 percent. After harvest, incoming dockage exceeding an average 2.1 percent were cleaned down to an average 0.8 percent.

The North Dakota survey also indicated that the cost of cleaning can range from 2 to 5 cents per bushel, depending on cleaner capacities (16), Since dockage is treated as a deduction to weight, transportation costs to the final destination and price for cleanings are critical when determining the economics of cleaning. Transportation rates as well as the price for cleanings have decreased in the mid-1980s. Multiple-car and unit-train shipments have reduced the cost of moving wheat from the Northern Plains States to the Pacific Northwest. When the cost of cleaning, transportation rates, and the price of cleanings are evaluated, the survey indicates that it is not economical to clean wheat in these areas unless dockage levels exceed 2 percent.

The amount of grain cleaning prior to storage revolves around the risk of grain deterioration as a result of mold and insect invasions and the costs associated with maintaining quality. The effects of mold and insects on grain quality, along with technologies used to maintain quality, are discussed in the section dealing with storage and handling technologies.

Fine material segregates in spoutlines, as discussed in other sections of this chapter. Hall (25) found that materials that pass through a 12/64-inch round-hole sieve segregate in spoutlines, while larger pieces rolled with the whole corn to the sides, This phenomena affects aeration since fine materials have higher airflow resistance than whole kernels, and the air detours around them, commonly causing overaeration.

Several other investigations on the effect of corn particle size on aeration have been conducted. Small pieces (12/64 inch in diameter and smaller) cause the most increase in airflow resistance during aeration, and the finer the particles, the more the resistance. However, the level of broken corn and foreign material present in the grain mass can also have an impact. Even though the impact of cleaning on dryer performance and storage technologies is well known, moisture content is the principal factor in decisions regarding storability and dryer performance, not cleaning.

New and Emerging Technologies

Aspiration cleaning is a relatively new technology being used in some wheat-producing areas to clean grain and remove insects. Multipass systems, in which grain is aspirated several times at progressively increasing air velocities, have improved efficiency. Aspiration cleaning will become more prevalent if clearly demonstrated to be capable of cleaning at normal production handling rates.

Several cleaners in Europe are arranged to use centrifugal force rather than vibratory motion or impact to cause screen separation. The one offered in the United States also has aspiration before the screens. The principle was designed to preclean wet grain before drying. With the majority of corn being dried on-farm, it is doubtful that a moderate capacity (4,000 to 10,000 bushels per hour) cleaner will penetrate the commercial market. However, it is a viable concept for preparation of specialty shipments and might be useful to clean corn after commercial drying.

Rapid sensing systems for physical properties open possibilities for on-line control of cleaning systems. No commercial devices of this type are available, but investigative work is being done.

Blending

Blending can be defined as mixing two or more grain lots to establish an overall quality that may or may not be different from any one individual lot. Blending occurs for three reasons:

1. there are economic incentives for grain to beat a specific quality, no better or worse;
2. the uniformity of the reblended product makes it better suited for handling, storage, or utilization; and
3. sometimes an aspect of a particular process requires a specific quality or range of quality in preference to other possible qualities.

Except for factors such as protein and falling number in wheat, the present U.S. marketing system does not normally emphasize user properties, so the first two explanations are the most applicable. However, as more user properties (e.g., protein, oil, and starch) become trading factors, situations will occur when a blended product will be more valuable to the user.

The central issue in blending is whether it has a positive or negative impact. The list of important quality factors can be divided into two categories: those that are defects (or will cause defects) and those that are specially tied to individual end use. The line is not always clear, but defect factors are of negative value to all users whereas user-sensitive factors will be evaluated differently, even oppositely, by different users. Primary examples of defect factors are foreign material and damaged kernels. As all defect factors have negative value, blending these factors will not improve the value of grain (29).

Blending can be neutral or even beneficial for user-sensitive factors such as protein in wheat. If the value of factors can be determined on a linear continuous scale (e. g., protein in wheat and soybeans and oil in soybeans), then deliberate blending will neither help nor hurt. However, if the premium scale is not proportionally sensitive, then blending may may not be beneficial. Processes may also have to be adjusted to make the most use of varying qualities (e.g., steeping time in wet milling or protein in wheat milling), which means that uniformity within the shipment as evidenced by test results clustered around some mean value will be preferred to random distributions.

Principles of Blending

Many States contribute to national wheat, corn, and soybean production. Weather, genetics, and agronomic differences virtually assure quality differences within and across crop years and contribute to the lack of uniformity within a particular grain. These differences exist for whatever factors are used to describe quality. For example, if an importer were to purchase wheat today, the shipment could be comingled with a multitude of varieties, from several regions, covering several crop years.

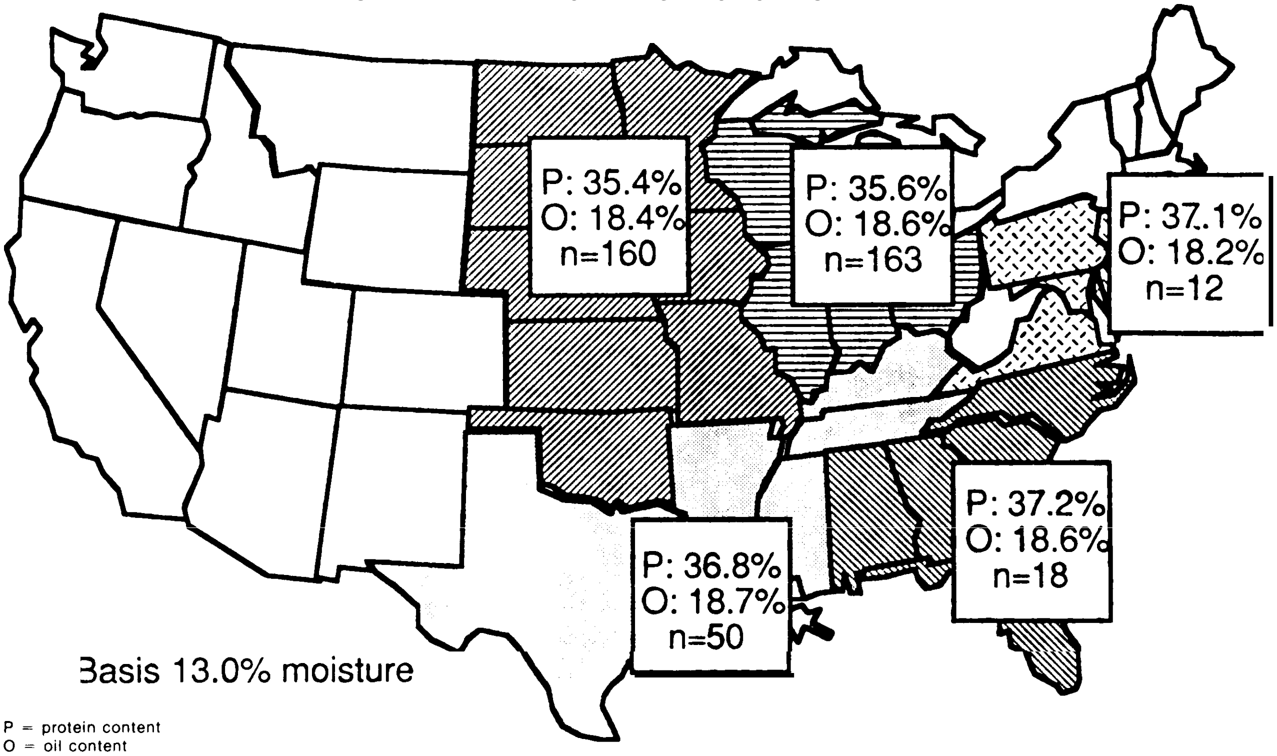
As intrinsic factors start to be measured and taken into account in the marketplace, the regionality problem will be magnified. Figure 7-16 presents data on regional soybean protein and oil. Blending will have to occur if fixed specifications are set. If soybean protein and oil are priced on a continuous scale with no mandatory targets, growers in some areas will face discounts relative to growers elsewhere,

The basic mathematics of blending are relatively simple. The quality of a blend is the weighted average of the qualities being blended. The application is straightforward when two or fewer are involved. If several characteristics have economic value, however, then a profit function must be set up in terms of all relevant factors. The optimum blending proportion is the one that yields maximum profit. Many other considerations—storage space, market expectations, shiploading plans, and so on—must be included. Linear program methods have been used to analyze complex blending problems (4 I).

If more than one factor is being controlled, then the blend is most easily optimized if the one quality factor is concentrated in all grain lots used in the blend. This minimizes the effect of blending for that factor and allows concentration on the others. When the levels for the factor are low, then concentrating on the individual factor being blended will minimize the number of secondary streams. This explains why cleaning and relending broken grains and/ or foreign material is preferred over blending two grain streams of differing percentages. It is also easier to hold a uniform blend when controlling a small flow rate of pure foreign material, pure damage, or clean, high-moisture grain.

U.S. grain-handling facilities are designed to store large masses of relatively uniform grain of some intermediate quality, with small special storage for lots concentrated in one quality factor (high moisture, high damage, high protein, etc.), although to a lesser degree in spring and Durum wheat-producing areas. This is possible because the most heavily traded grades allow the majority of the grain to fall within broad limits and thus be stored en masse. As additional quality factors are introduced, this design and management philosophy will present more difficulties, since there will be more factors to consider in profit maximization. In-

Figure 7-16.–U.S. Soybean Quality by Region, 1986



SOURCE. American Soybean Association, 1987

trinsic factors cannot be as readily concentrated or manipulated as physical factors.

Current Procedures

Premiums and discounts can encourage or discourage blending and are set by merchants subject to buyers' needs and supply conditions. For example, high-damage corn is more likely to be directed to export for blending into No. 3 than to a domestic processor buying No. z. Likewise, poorer quality soybeans are more apt to fit in No. 2 export cargoes than in No. 1 purchases by domestic processors. On the other hand, protein in wheat can be directed to either the domestic or the export market using protein premiums and discounts.

A case in point is protein content in spring wheat using March 1988 protein premiums and discounts in both the Pacific Northwest and Minneapolis markets. The base protein value markets is 14 percent, In the Pacific Northwest, protein premiums of 3 cents were being paid for each 0.25 percent over the base, whereas 6-cent discounts were applied to shipments under the base, At the same time, in the Minneapolis market premiums of 5 cents were paid for every 0.2 percent over the base with discounts of 3 cents being applied for shipments under the base. With such a schedule, a shipper would be better off blending protein levels for shipment to the Pacific Northwest and shipping 13 and 15 percent shipments separately to the Minneapolis market.

Grain handlers do not solve complex mathematical formulas to adjust blending proportions as they move grain. Table 7-9 shows a typical example of four soybean lots being combined to make a U.S. No. 2 grade. The equal-proportions blend would not necessarily be the high-

Table 7.9.—Blending of Four Soybean Lots to Make U.S. No. 2, Maximum 13% Moisture

Lot	Moisture (percent)	FM (percent)	Damage (percent)	Value[a] (dollars per bushel)
1	11.5	1.0	1.0	6.00
2	14.5	1.2	1.0	5.82
3	12.5	1.0	5.0	5.94
4	11.5	4.0	1.0	5.88
Average value				5.91
Blend of equal proportions	12.5	1.8	2.0	6.00
Contract specification	13.0	2.0	3.0	6.00

[a]Based on typical discount schedules relative to U.S. No. 2. base Price of $6.00/bu.

SOURCE: C.R. Hurburgh, "The Interaction of Corn and Soybean Quality With Grain Storage," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

est profit one, but is quite common. If the foreign material were removed and reblended as pure foreign material, more wet soybeans (lot z) and more damaged beans (lot 3) could be blended without exceeding specifications. Likewise, if lot 3 were more concentrated in damage, it would exert more effect on the damage percentage and less on other factors. Overall, however, profits from blending are possible only if the average quality of grain normally exceeds specifications. The closer the specifications are to the available average quality, the less the potential for blending.

Operationally, blending is accomplished with varying degrees of sophistication. At export, barge, and major inland terminals, grain is continuously sampled with a mechanical diverter as it is being loaded. Samples are analyzed and changes to the mix can be made. Generally, the facility manager will target quality somewhat better than the specifications to protect against the chance that normal variability in loading, sampling, and analysis will yield a result exceeding specifications.

Modern facilities have proportioning gates that control the flow of individual qualities to the blend. If the facility is equipped for any of the cleaning/reblending options discussed in the cleaning section, cleaner throughput and relending rates will also be controlled from the loadout control center. Older facilities do not have continuous sampling and automated flow control.

Quality Factors Affected by Blending

Moisture.—The primary reason for moisture blending is purely economic, and it is most common at interior locations where high-moisture grain is more available. Handlers and growers routinely capitalize on cold weather to store moderate-moisture corn (up to 20 percent) and soybeans (up to 15 percent). Furthermore, carryover stocks from previous years are usually much drier than market limits, offering an opportunity for blending with fresh wet grain from the field at harvest. Moisture blending can cause grain deterioration, as discussed in the storage and humidity technologies section of this chapter.

Particle Size.—Blending for particle size factors has stirred the most controversy because these include dockage, foreign material, and dust. As discussed in the cleaning section, corn and soybeans break during each handling, creating foreign material and dust. This is compounded by the fact that corn breakage susceptibility increases about 40 percent for each 1-percent reduction in moisture (19). Soybean breakage susceptibility increases 22 percent for each l-percent reduction in moisture (32). Breakage is not the critical factor in wheat. However, since dockage in many areas of the country is not removed, each handling generates dust, which is collected. Therefore, blending of these factors is essentially a defensive operation to minimize the economic effects of constant handling, breakage, and dust generation.

As mentioned in other sections of this chapter, as grain is loaded, fine material concentrates in the center of a grain mass and uniformly blended grain streams will not stay uniform once loaded because fine material segregates. No amount of blending will eliminate this problem.

Kernel Damage.—Blending damaged kernels is a purely economic operation that exists because normal damage levels are less than allowed in specifications. Corn is harvested with about 2 percent damaged kernels, soybeans normally with less than 0.5 percent, and wheat well within the limits of No. 1 (2.0 percent). Grade limits for damaged kernels in export shipments of No. 3 corn (7 percent), No. 2 soybeans (3 percent), and No. 2 wheat (4 percent) are wide enough to accommodate blending of any unusual or storage-damaged lots.

INTERACTIONS/FINDINGS AND CONCLUSIONS

Grain is a living, breathing organism and as such is a perishable commodity with a finite shelf life. The best harvesting, drying, storing, handling, and transporting technologies in the world cannot increase quality once grain is harvested. Each technology is a self-sustaining operation, but the way each is used affects the ability of the others to maintain quality. For example, if grain is harvested wet, not only will this lead to increased breakage during harvesting, but it means the grain must be dried. Improperly used dryers means more breakage and nonuniform moisture content. Moisture content, uniformity of moisture content, and the amount of broken grain and fine materials affects storability and can have an impact on the technologies used to maintain quality during storage. Therefore decisions made at harvest, as well as at each step thereafter, influence the system's ability to maintain and deliver a quality product,

As discussed throughout this chapter, grain moisture and amount of broken grain and fine materials stand out as the two critical factors affecting the performance of each technology.

Moisture

Moisture at harvest directly affects the amount of kernel damage produced through combining. For corn, physiological maturity is obtained at about 30 to 35 percent moisture. Although corn can be harvested at this point, it is damaging to the kernel's soft pericarp and is not recommended. In the Midwest, it is generally recommended not to harvest until the corn has field-dried to 26 percent moisture. However, obtaining a 26 percent moisture in the Northern States is not possible during wet fall harvest periods, and corn must be harvested at higher moisture contents or it will not get harvested at all,

Since cereal grains and oilseeds are harvested in the United States at moisture levels that are too high for long-term storage or even short-term storage and transportation, these commodities must be dried to acceptable moisture levels. Corn, harvested at 20 to 30 percent moisture, must be dried to 14 to 15 percent for safe storage. Wheat and soybean harvest moistures are substantially lower, with their safe storage levels marginally lower than harvest moisture. In certain regions of the United States, wheat dries naturally in the field. In some cases this is also true for soybeans.

The process of drying has a greater influence on grain quality than all other grain-handling operations combined. For superior grain quality, it is imperative to optimize dryer type and operation since half the corn crop is dried in continuous-flow, portable batch, and batch-in-bin dryers of the crossflow type. Of particular concern is the increase in breakage of corn and soybeans and the decrease in milling quality of wheat. Artificial drying of wheat and soybeans, however, is not frequently required.

The main dryer operating factors affecting grain quality are air temperature, grain velocity, and airflow rate. Operators can adjust the first two on every dryer and, on some units, can adjust all three. Collectively, the three conditions determine the drying rate and maximum temperature of the grain being dried, and thus establish the quality of the dried lot.

Over ***80*** percent of the United States corn crop is dried on farms. On-farm dryers fall into three categories—bin, non-bin, and combination dryers. Bin dryers are in general low-capacity, low-temperature systems, able to produce excellent quality grain. Non-bin dryers, the most popular dryer type, are high-capacity, high-temperature systems that frequently overheat and overdry the grain, and thereby cause serious grain-quality deterioration. Combination drying combines the advantages of both systems (i.e., high capacity and high quality) but requires additional investment, and is logistically more complicated. A switch by farmers from non-bin to combination drying would significantly improve U.S. corn quality,

Off-farm dryers fall into three classes—crossflow, concurrent-flow, and mixed-flow dryers. All are high-capacity, high-temperature units. In the United States, crossflow models are the most prevalent; they dry the grain non-uniformly and cause excessive stress-cracking of the grain kernels. Mixed-flow dryers are common in other major grain-producing countries; the grain is dried more uniformly in these, and is usually of higher quality than that dried in crossflow models. Concurrent-flow dryers have the advantage of producing the best quality grain; their disadvantages are the relatively high initial cost and the newness of the technology. A change from crossflow to mixedflow/concurrent-flow dryers will benefit U.S. grain quality.

Moisture content and uniformity within a storage facility are critical to maintaining grain quality, as demonstrated by the Allowable Storage Time Table for corn. The interaction between moisture, temperature, and relative humidity spurs mold growth, increases insect activity, and causes other quality losses. Basically, grain moisture in equilibrium with 65 percent relative humidity will support mold activity, but different grains will create the equilibrium relative humidity at different moisture levels. That is why wheat and soybeans cannot be stored at the same moisture content as corn. In the case of controlling insects, high moisture contents increases absorption of fumigants such as methyl bromide, requires an increase in dosage, and accelerates the breakdown of protective treatments such as malathion.

The equipment and methods used to fill a storage bin affect the performance of aeration systems used to control the effects of moisture/temperature/humidity. Dropping grain into the center of a bin causes a cone to develop, with the lighter, less dense material concentrating in the center (in spoutlines) while the heavier, denser material flows to the sides. This impedes airflow during aeration, and molds can begin to grow almost immediately.

In large horizontal storage areas, loading from the center or from a loader that is gradually moved backward through the center of the building as the pile is formed causes similar problems, If grain is piled over each aeration duct on the floor by moving the loading device back and forth, airflow will be greatly increased. However, airflow distribution is not as uniform as in upright bins. Some methods of filling piles also result in fine materials concentrating in local areas. These accumulations are more subject to insect and mold growth, and they divert airflow. But piles are difficult to aerate, and the shape of some restricts uniform airflow.

Nonuniform moisture levels can lead to spoilage in localized areas within a storage facility. Even assuming that moisture and temperature are uniform within a grain mass, they will not remain so over time. Moisture will migrate in response to temperature differentials. If the outside air is warmer than the grain, the circulation reverses, and the area of condensation is several feet under the grain surface, but still in the center.

The effect of moisture migration on storage is that grain assumed to be in a storable condition will not be. Cold weather migration primarily affects grain in land-based storage, causing deterioration as temperatures rise in the spring. Warm weather migration is particularly vexing for grain in transit both from cold to warm areas of the United States and from the United States through warm waters to foreign buyers, A barge or ocean vessel is basically a storage bin and will experience the same migration phenomena as land-based storage facilities.

Broken Grain and Fine Materials

Three factors—cylinder speed, moisture at the time of harvest, and amount of grain damage—are interrelated. In general, whenever grain is harvested, damage or breakage occurs. However, grain damage is much greater in each case on extremely wet or extremely dry grain. When grain is harvested at high moisture levels, the kernel is soft and pliable. Moist kernels deform easily when a force or impact is applied, and greater force is needed to thresh wet kernels than dry ones, Thus, wet kernels suffer more damage than drier kernels. However, drier kernels can break when the same force is applied. Therefore, optimal conditions exist for each grain.

In addition to grain breakage due to moisture content, factors such as weed control and kernel density, especially in wheat, also affect a combine's ability to harvest and deliver clean grain. Cutting below the lowest pod or wheat head inadvertently introduces some soil into the combine. Most soil is aspirated from the rear unless there are soil particles about the same size as the kernel, in which case they pass through the cleaning sieves with the grain.

Harvesting technologies normally remove material larger than the grain (such as plant parts) and material significantly smaller (like sand and dirt). Sloping terrain, however, can affect this process. Side slopes also create problems since the tendency is for material to congregate on the downhill side of the cleaning shoe.

The main factor affecting the combine's cleaning performance is the amount and type of weeds present in the field during harvest. Weed control is one of the most serious problems facing many wheat producers in the United States. This is also true for Southeastern U.S. soybean-producing areas, where a warm wet climate is conducive to weed growth, The amount of weeds affects not only yield, but also the amount of foreign material present in the harvested grain and the combine's ability to remove this material.

Combines are being modified to improve performance in weedy fields. In the case of wheat, kernel size has been decreasing, which complicates this modification. The trend toward smaller kernel size is a concern because the seeds of most grassy weeds are smaller and lighter than wheat, Thus, smaller wheat kernel size reduces the margin between wheat and weed size and, therefore, increases the difficulty of cleaning within the combine.

As discussed in the drying technology section, rapidly drying moist grain with heated air causes stress cracking. The drying operation itself does not cause grain breakage, but can make grain more susceptible to breakage in later handlings. Cleaning grain before it reaches the dryer can improve dryer efficiency. Introducing clean grain to the dryer:

- results in a more uniform airflow in the dryer and thus a more uniform moisture content of the dried grain;
- decreases the static pressure (airflow resistance) of the grain, thus increasing the airflow rate and dryer capacity; and
- eliminates the drying of material that detracts from final grain quality,

Obviously, precleaning also has disadvantages. It requires additional investments in cleaners, the handling of wet broken corn and fine material, and the rapid sale of wet, easily molding material, and it results in some dry matter loss. Although the advantages of precleaning wet grain are fairly well understood by dryer operators, most do not preclean. The quality of U.S. grain would improve substantially if precleaning were adopted,

Mechanical damage during handling results in grain breakage, which produces broken grain and fine materials, This causes a decrease in quality, greater storage problems, and an increase in the rate at which mold and insects invade stored grain, Research has shown that breakage in handling is more significant for corn than for wheat and soybeans. Higher moisture content and higher temperatures prove to be the optimum conditions to minimize breakage but are opposite of the optimum safe storage moisture and temperature. The effect of repeated handlings on grain breakage is cumulative and remains constant each time grain is handled or dropped. This is true whether or not broken material is removed before subsequent handlings.

The impact of grain breakage and fine materials on all aspects of the system has resulted in the need to clean grain. Cleaning wheat in commercial handling facilities is normally limited to removing dockage, insects, and to a limited degree shrunken and broken kernels. For corn, cleaning regulates the amount of broken kernels and foreign material, and for soybeans, the amount of foreign material and split soybeans.

Cleaning corn to remove broken corn and foreign material is required at each handling in order to meet contract specifications and avoid discounts. For wheat, however, the majority of the dockage is generated during harvest and normal handling does not cause significant increases. Therefore, cleaning is not required at each handling. Soybeans, on the other hand, fall somewhere in between regarding their breakage susceptibility and the amount of cleaning required at each handling.

The amount of grain cleaning prior to storage involves the factors of risk to grain deterioration as a result of mold and insect invasions and the costs associated with maintaining quality. In the case of fumigation: broken grains, grain dust, and other fine materials have the greatest effect on the performance of insect control interventions. When a protective treatment is applied, grain dust may absorb much of the insecticide, which reduces the effectiveness. Likewise when a fumigant is applied, concentrations of dust and fine material may require increased dosages to penetrate the grain mass. Dust also inhibits penetration of fumigant gases and causes the gas to channel so that penetration is slow or stopped in certain parts of the grain mass.

Ability of System to Maintain Quality

Technologies are in place to harvest, maintain, and deliver quality grain. Each technology must be used, however, in a manner conducive to maintaining grain quality.

Although data indicate that nearly any combine can deliver acceptable quality, farmer-operated combines tend to have higher levels of grain damage than the combine should deliver. From a technology standpoint two areas need emphasis:

1. greater education efforts to help operators better understand the interactions of cylinder/rotor speed, concave openings, fan speed, and sieve openings with grain quality and grain losses; and
2. more monitoring devices and possible automatic controls on combines-to help operators adjust or fine tune the combine.

Weed control and its relationship to kernel size and density are critical to optimum combine performance. Unless new technologies addressing this area are developed or better weed control measures for use by the farmer are forthcoming, the combine's ability to harvest and clean grain will continue to present problems.

A significant improvement in grain quality can be obtained by optimizing the dryer operating conditions of existing crossflow dryers, by precleaning wet grain, by selecting the best grain genotypes, and by installing automatic dryer controllers.

Molds will grow on any kernel or group of kernels that provide the right conditions. Therefore, moisture content and moisture uniformity within storage facilities are critical to maintaining grain quality. Maintaining low temperatures and moisture levels in grain are the principal ways to preserve grain quality and prevent damage from molds and insects. Aeration is also a very effective tool. The rate of development of both molds and insects is greatly reduced as temperature is lowered.

Many storage bins, especially on the farm, are equipped with aeration systems that are often not used effectively. Farm storage bins, especially smaller and older ones, often are not aerated. Small bins will cool or warm with the changing season quickly enough that moisture condensation may not be a serious problem, A majority of farm aeration systems are either not operated at all or not used enough. The most common problem is not running the fans long enough to bring the entire grain mass to a uniform temperature level. If a cooling front is moved through only part of the grain, a moisture condensation problem is likely at the point where the warm and cold grain meet.

In addition to aeration, the turning and transfer process mixes grain and contributes to a more uniform moisture and temperature. In facilities not equipped with aeration, turning has been the traditional means of grain cooling. However, turning requires much more energy to cool grain than aeration does, and it can contribute to physical damage by breaking the kernel,

Turning grain cannot be performed in horizontal or pile storages because of the difficulty in unloading and moving the grain. In order to turn grain, a handling system must have empty bins connected by a conveying system. This is not the case on most farms.

Most grain storage facilities provide a natural habitat for stored-grain insects even when the facility is empty. Grain residue in floor cracks and crevices, wall and ceiling voids, and ledges provide an ample supply of food to sustain several insect species. Thorough cleaning is the first and most effective step toward preventing insect infestation of freshly harvested grain. Because insects live from season to season, cleaning and removing trash and litter is important. Also, a thorough cleaning should precede any insecticidal treatment of storage facilities if the full value of the treatment is to be expected.

For several reasons—such as remoteness of farm storage facilities, small amounts of grain to be treated, and lack of information—farm storage facilities are inadequate to receive an insect control treatment. Therefore, when grain that has not received a properly applied treatment is marketed, it becomes mixed with noninfested grain and magnifies the problem, thus creating greater loss and the need for more expensive and time-consuming remedies,

The high-speed, low-cost U.S. grain system does not readily accommodate special quality needs. While these needs can be met by slowing belt speed, installing and using cleaning equipment, eliminating unneeded handlings, and preserving the identity of grain, most of these actions increase costs.

All the factors affecting quality just discussed —nonuniform moisture, moisture migration, temperature and humidity, insect invasion, and mold development—have an impact on grain quality during shipment. No mode of transportation is equipped with aeration, nor can grain temperatures and corrective actions be taken during shipment. And moisture migration can be more dramatic during shipment since grain can undergo several outside air temperature and humidity changes, This is especially true when grain is loaded in a cold climate and transported through warm water rather quickly to a warm humid climate. Therefore, moisture uniformity is critical to maintaining quality during shipments.

The interactions between technologies regarding moisture content and breakage on grain quality are evident. Each technology is capable of preserving grain quality. Once inert material such as weed seeds, dirt, stems, cobs, and so on are cleaned out of grain, no further cleaning is required. But grain, especially corn, must be cleaned to overcome breakage due to handling in the system and is inevitable. Once grain quality deteriorates at any step in the process, it can never be recovered. As demonstrated by the Allowable Storage Time Table for corn, shelf life is a time line with a certain share expended at each storage condition, Once this time has passed, there is no way to recover what has been lost.

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